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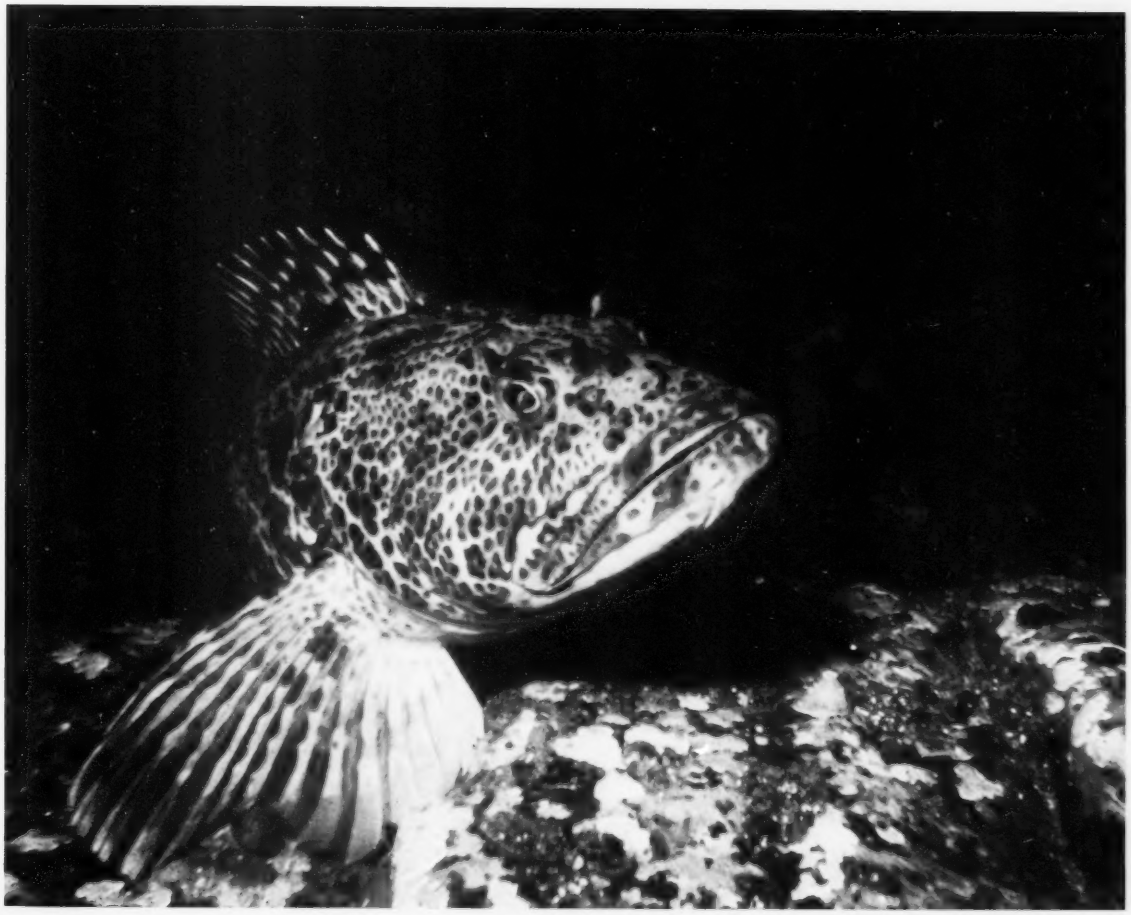

Lingcod

Marine Fisheries REVIEW

On the cover: A lingcod.
Photo by William L. High,
NMFS, Seattle, Wash.

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Tuna Fisheries in the Federated States of Micronesia, 1979–90.

J. H. DIPLOCK

Introduction

The Federated States of Micronesia (FSM) is a sovereign nation consisting of more than 600 islands lying between the equator and lat. 14°N in a band from long. 135°E to 166°E in the tropical western Pacific Ocean (Fig. 1). The Exclusive Economic Zone (EEZ) encloses more than 2,978,000 km^2 of ocean, including some of the world's richest tuna fishing grounds, and is fished by mostly foreign pole-and-line, longline, and purse seine fleets.

Since 1979, when a management regime was introduced, the catch has risen substantially, and there have been significant changes in fleet size and composition. With a land area of only 271 mi.^{2} and a population of about 100,000 (Anonymous, 1990a), the economy relies heavily on revenues derived from fishing. Initially, the aim of management was to maximize revenue from license fees. The number of vessels was not restricted and license fees grew to comprise a major portion of the national revenue. The introduction of purse seining and the rapid increase in landings led to concern over possible overexploitation and the effects of fishery interactions. Management objectives now emphasize stock assessment and the evaluation of the effects of fishing as well as securing an equitable return from foreign vessels.

This paper outlines tuna fishery developments and changes in management aims since 1979. The status of stocks is reviewed and the approach to setting harvest levels is discussed.

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ABSTRACT—The management of tuna fisheries in the Federated States of Micronesia since independence in 1979 is reviewed, noting the development, seasonality, and geographic range of the fisheries. The status of stocks, including trends in catch per unit effort and the approach to setting harvest levels for the major species, are also reviewed. Future developments and management aims are discussed.

The Fisheries

Prior to 1979

Commercial tuna fishing in Micronesia was initiated by the Japanese after they took control of the region from Germany at the start of World War I. The Japanese surveyed the resource in the 1920's (Smith, 1947) and began pole-and-line fishing from Palau in 1925. By 1937 the catch of skipjack tuna, *Katsuwonus pelamis*, in Micronesia had reached 33,000 metric tons (t), with 12,433 t landed in Chuuk and 4,064 t in Pohnpei (Wilson, 1971). The fishery was interrupted by World War II and resumed in the late 1950's with vessels carrying bait from Japan. During the 1960's, the pole-and-line fishery produced about 30,000 t per year (Skipjack Programme, 1980), and catch rates remained high during the 1970's (Anonymous, 1978), peaking at about 50,000 t per annum in 1976 when effort was high. Japanese longline vessels targeting yellowfin tuna, *Thunnus albacares*, began to fish Micronesian waters in the early 1950's. They were followed by Korean and Taiwanese longliners in the late 1960's (Skipjack Programme, 1981).

Several purse seine pilot studies undertaken by Japanese and U.S. fishermen in the early 1970's led to the introduction of large-scale purse seining in the region in 1980 (Anonymous, 1980). The development of purse seining up to 1981 is detailed by Franklin.[1]

The FSM fisheries are seasonal and characterized by temporal changes in vessel numbers, type, and flag. A brief description of each fishery since 1979 is given below.

Pole-and-line

The foreign pole-and-line fleet in the FSM has consisted exclusively of Japanese vessels. Fleet size has decreased from a high of 200 vessels in 1979 to 58 vessels in 1989 (Fig. 2). Vessel size has increased from 402 gross tons (GT) in 1985 to 458 GT in 1990. Fleet efficiency has improved with automation and the addition of poling machines. The enhanced quality of the catch has allowed higher returns from market diversification. Although vessel efficiency has improved, fleet size is expected to decline as vessels are not being replaced.

The pole-and-line fishery is seasonal with little activity in FSM waters during the boreal summer (June to August). The most intense fishing occurs from February to March. Effort is generally concentrated east of long. 150°E between lat. 2°N and lat. 10°N but is variable between years. The catch is predominantly skipjack tuna (99%) with a small bycatch of yellowfin tuna (1%). Catch rate has averaged 6.4 t per boat per day. Since 1979 the catch has fluctuated from a low of 2,190 t in 1982, when the Japanese were excluded from the EEZ, to a high of 31,700 t in 1986 (Fig. 3).

[1] Franklin, P. 1981. Southwestern Pacific skipjack and purse seine fishery-development-current status-future. Forum Fish. Agency, Honiara, Solomon Isl., Unpubl. rep. FFA/IN 11, 24 p.

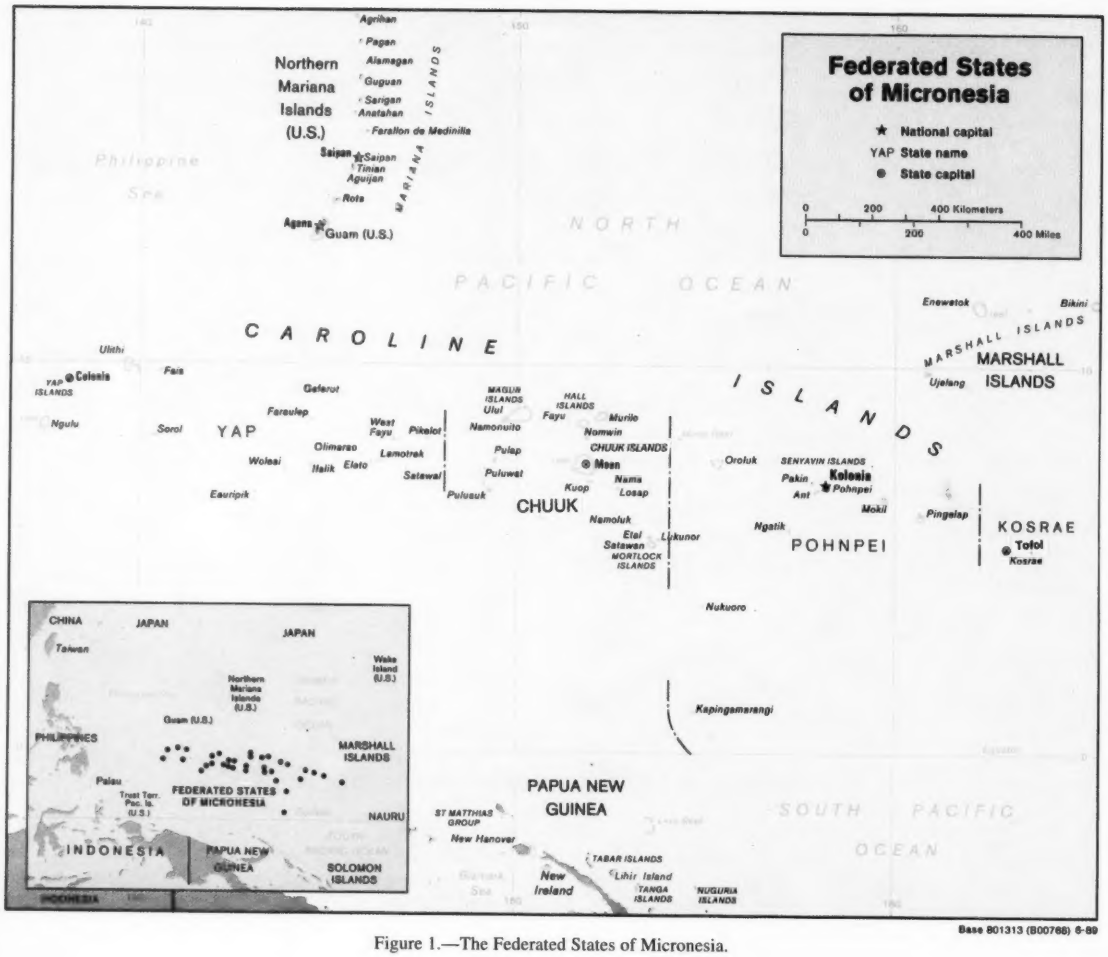

Figure 1.—The Federated States of Micronesia.

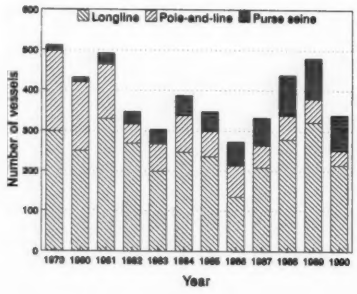

Figure 2.—Number of tuna vessels by gear type from 1979 to 1990.

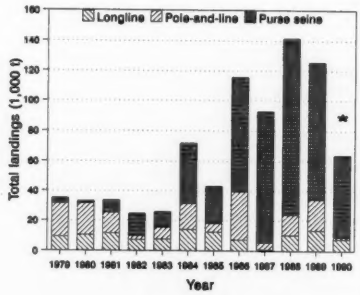

Figure 3. —Total landings (t) by gear type for the years 1979–1990. The asterisk(*) indicates data for the period January 1989 to August 1990 only.

Longline

Longlining in the FSM is also dominated by the Japanese. In 1979, almost 900 permits were issued to Japanese longliners, but less than half that number actually fished in the zone. Since 1979, fleet size has varied from more than 320 vessels in 1981 to less than 130 in 1986 (Fig. 2). From 1979 to 1987, most vessels ranged from 59 to 69 GT, with about 5% of the fleet composed of vessels less than 20 GT. Since then the number of small longliners has increased. In 1989, 28% of the fleet were vessels <20 GT. In 1989 about 250 Japanese and 60 Taiwanese longliners entered the zone.

Japanese vessels <20 GT generally fish between lat. 4°N and 10°N and west of long. 156°E. Japanese vessels >20 GT fish in two separate areas. The area of most intense fishing lies south of lat. 6°N to the edge of the EEZ and extends the full width of the zone from long. 135°E to 166°E. A band of less intense fishing lies north of lat. 8°N and extends from long. 140°E to 158°E. Between these areas, fishing effort is much less intense. The Taiwanese fleet operates mostly in the western part of the zone between lat. 3°N and 9°N and as far east as long. 150°E.

The Japanese longline fishery is seasonal with highest catches during the spring and summer months. The total annual catch for vessels <20 GT is usually less than 1,000 t, while vessels >20 GT land between 8,000 and 9,000 t per annum. The Taiwanese fleet operates mostly from July to December, and although catch reporting is poor, the annual catch is estimated to be more than 1,000 t. The average number of hooks set by Taiwanese longline vessels is about half the number set by Japanese vessels. The total longline catch has fluctuated between 13,188 t in 1984 and 7,128 t in 1986 (Fig. 3).

Purse Seine

The purse seine fishery has grown rapidly in terms of fleet size and catch (Fig. 2, 3). The number of vessels licensed has increased from 14 in 1979 to 112 in 1989, including 39 Japanese (32 single and 7 group) seiners, 15 Taiwanese (13 single and 2 group) seiners and 32 U.S., 18 Korean, 3 Indonesian, 3 Vanuatu, and 1 Australian (all single seiners).

Purse seine effort is concentrated in the southern part of the EEZ south of lat. 6°N. The Japanese and Taiwanese fleets tend to operate in the western part of the zone, west of long. 154°E, but the area is variable between years. The Korean fleet operates south of lat. 5°N between long. 150°E and 160°E. U.S. purse seiners fish mostly in the south of the EEZ close to the Papua New Guinea (PNG) zone and international waters.

The purse seine fishery is seasonal. Maximum activity is between March and July, when the Equatorial Counter Current moves north bringing more flotsam to the zone.

Management

Organization

After WWII, what is now the Federated States of Micronesia, together with Palau, the Northern Mariana Islands, and the Marshall Islands, belonged to the Trust Territory of the Pacific Islands (TTPI) administered by the United States under mandate from the United Nations. Fisheries management was not actively pursued until the Fishery Zones Jurisdiction (Title 52 of the Trust Territory Code pursuant to Public Law 7-71) covering the TTPI (except for the Northern Marianas) came into force on 1 January 1979 establishing an Extended Fishery Zone (EFZ) of 200 n.mi. breadth from the low tide. mark or outer reef line (Buchholz, 1987).

When internal self-government was granted to the FSM on 10 May 1979, the FSM sought to maintain jurisdiction over the EFZ and garner income from the rapidly developing fisheries in its waters. The Micronesian Maritime Authority (MMA), hitherto a TTPI entity, was reorganized as an FSM instrument to undertake fisheries regulation and accrue revenue from license fee collection. The primary objective of the MMA then was to maximize the net return of fisheries to the national income by way of fishing access fees. This mandate was pursued effectively throughout the 1980's. At the same time, detailed catch and effort information was collected as part of the fee determination process and to provide comparative data for stock assessment.

In 1989, a 200 nautical mile EEZ was proclaimed, and a revised Title 24 of the Code of the Federated States of Micronesia empowered the MMA to have the following authorities, duties, and functions:

1) To adopt and promulgate regulations for the conservation, management, and exploitation of all living resources in the EEZ of the FSM;
2) To negotiate or conclude foreign fishing agreements;
3) To issue foreign fishing permits;
4) To rebate according to regulation approved by the Authority, all or portion of a fee from joint fishing ventures in the FSM;
5) To participate in the planning and execution of programs relating to fisheries, or fishing in the EEZ in which any agency of the FSM government has proprietary interest, direct or indirect, by way of stock ownership, partnership, and joint venture;
6) To provide technical assistance in the delimitation of the FSM EEZ; and,
7) To perform other duties and functions as may be required or necessary to carry out the purpose of Title 24.

The new Act required the MMA, for the first time, to assess the current level of fishing on the stocks.

Access Agreements

Initially, the MMA focused on obtaining recognition from foreign countries of FSM jurisdiction over its fisheries resources. Having established the principle of payment for access, the MMA required foreign vessels to pay license fees to fish within the EFZ and later the EEZ. To achieve this access, negotiations were undertaken with fishing companies and associations of distant-water fishing nations (DWFN's) on a bilateral basis.

The MMA sought to ensure a fair return from the resources, and access

fees collected from foreign fishing vessels rapidly increased after 1984 (Fig. 4). Since 1987, purse seiners have contributed most license fee revenue as catches have increased. Although the longline catch remains relatively small, longliners generate significant revenues due to the high fees based on the value of their landed catch (Fig. 3, 4). In 1989, fees for fishing access contributed more than 61% of the FSM domestic revenue and 25% of total national revenue. Most of the remainder comes from the U.S. aid provided under the Compact of Free Association.

The first access agreement between FSM and a DWFN was signed with the Japanese Fisheries Association in 1979. The agreement was based on a lump-sum payment system whereby vessels paid a single fee to operate in the EEZ during the agreed period. A per-vessel-per-trip (PVPT) system was introduced in 1984. Under the PVPT system, vessels pay an annual registration fee and a permit fee each time they enter the EEZ. The permit fee is derived from the quantity and price of the major species at the Japanese ports where fish taken in FSM waters are landed, combined with estimates of the average catch per trip and a royalty factor. The Japanese have had continuous access to the zone except for two periods from January to May 1982, and from August 1983 to January 1984 when agreement could not be reached on fee levels.

Japan has been the major contributor of fishing access fees. This is due both to the duration of access agreements and the high value of the landed catch, particularly that of longliners. The value of access fees from DWFN's since 1979 is detailed in Table 1.

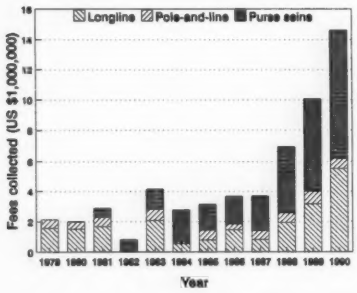

Figure 4.—Fee collection by gear type from 1979 to 1990.

Table 1.—Total access fees from Distant Water Fishing Nations from 1979 to 1990.

Country	Access fee ($US)
Japan	30,863,063
United States	3,793,740
Guam-based Japanese vessels	1,492,000
Taiwan	1,384,500
Republic of Korea	1,232,394
Indonesia	120,000
Mexico	100,000
Philippines	53,000
Australia	52,000
Solomon Islands	3,000
Others	21,600
Total	39,067,597

Taiwan, like Japan, historically fished in the region now covered by the FSM EEZ. The first fishing access agreement with the Taiwan Provincial Fishermen's Association (TPFA) was effected in 1979 with the licensing of more than 30 small longline vessels under a lump-sum payment system. In mid 1982, two Taiwanese group seiners were licensed to operate in the EEZ. The purse seine fleet, with increasing numbers of vessels, had access to the zone up to 28 February 1990. The Taiwanese longline fleet did not seek access to the EEZ from 1981 until the end of 1984. They were readmitted from 1985 to February 1990. All Taiwanese agreements were under the lump-sum system. The access agreement with the TPFA expired at the end of May 1990 and was not renewed. Through a special arrangement between a foreign company and the Pohnpei State Economic Development Authority, 9 Taiwanese longline vessels based in Pohnpei were licensed in 1991.

The licensing of a single purse seiner in November 1980 marked the establishment of a fishing access agreement with the Republic of Korea (ROK). In 1982, further purse seine vessels were admitted, and by early 1989, 19 single seiners were operated by ROK companies in the EEZ. Since then the fleet has expanded rapidly, and 32 vessels were licensed in 1990. Almost all the ROK purse seiners are second-hand vessels bought from the United States, Japan, and Mexico. Current catch estimates for the ROK fleet place them third behind the Japanese and U.S. purse seine fleets. All agreements with ROK were under the lump-sum system. There has been no fisheries access agreement with ROK since July 1990, despite numerous negotiations.

In 1981 the FSM, Republic of the Marshall Islands, and Palau entered into a multilateral arrangement with the American Tunaboat Owners Association (ATA). This was to circumvent the then U.S. government policy of not recognizing individual country's claims to "highly migratory species" such as tuna. The agreement lasted until 1982. From 1983 to 1984, the Republic of Kiribati joined the multilateral arrangement, but the Republic of the Marshall Islands chose not to participate. After 1984, no agreement was reached between FSM, Palau, Kiribati, and the ATA. The major issues preventing continuation of the agreement were fee levels and reporting requirements. From 1985 until the middle of 1988 there was no multilateral agreement with the ATA, and the FSM licensed individual U.S. vessel owners and issued short-term permits.

In 1984, the U.S. government and the Forum Fisheries Agency member countries, including the FSM, began negotiating a multilateral fisheries agreement to allow U.S.-flagged vessels access to their EEZ's. This initiative was prompted by the absence of access agreements and the repeated fisheries violations by U.S.-flagged vessels in the EEZ's of Pacific island nations. A multilateral approach was considered to be the only way to overcome the U.S. government tuna policy. The Regional Treaty on Fisheries between the Governments of Certain Pacific Island States and the Government of the United States was signed in Port Moresby on 2 April 1987 and put into effect on 15 June 1988. It was a 5-year agreement worth about $60,000,000, of which 15% was to be shared equally between the parties to the agreement. The remaining 85% was allocated in proportion to the volume of catch taken in each party's EEZ. During the first agreement period, 15 June 1988 to 14 June 1989, there were about 35 vessels

licensed through the treaty. The FSM received $2,200,195.

In the western Pacific, the U.S. fleet ranges from Kiribati in the east to Palau in the west and from the FSM in the north to New Caledonia in the south. Although their traditional fishing grounds have been in the eastern Pacific, it is likely that they will shift back and forth between the eastern and western Pacific fishing grounds in response to oceanographic conditions, such as El Niño, which affect the catchability of tuna. The U.S. purse seine fleet consists of about 100 vessels, and 49 vessels operated in the western Pacific in 1990.

The FSM has entered into bilateral agreements with several other countries. Two lump-sum agreements covering purse seiners were made with a Philippine company in 1984. Two more agreements were made in 1986. The Philippine purse seiners are small vessels designed to fish close to shore-based facilities and around "payaos" (floating fish aggregating devices), deployed close to the shore. Because of their limited size, the fleet can only operate in the FSM EEZ if they utilize an island transshipment point or employ carrier vessels for transshipment at sea and for provisions. The latest agreement involved fish carriers and was based in PNG.

From 1986 until 1989 there was an agreement with an Indonesian-based company covering three single seiners of 600 GT. The arrangement was not renewed due to problems with compliance on catch data.

Mexican-flagged purse seine vessels came to the region in 1983 when U.S. purse seiners shifted their operations to the western Pacific. They were not included in the U.S. multilateral arrangement, and the company representing the vessels signed a 1-year bilateral agreement in 1984. The agreement was extended for another year in 1985. In 1986 the vessels returned to the eastern Pacific.

Three Australian companies entered into short-term arrangements covering small purse seiners during the early part of 1989. In 1990, six vessels were licensed under an agreement with the Tuna Boat Owners Association of Australia.

In 1985 the MMA entered into an agreement with a Solomon Islands company to license several 59-GT longline vessels that had been given to the Solomon Islands as foreign aid by Japan. The vessels performed poorly and were subsequently sold. In 1989 a single seiner under charter by Solomon Taiyo Ltd.[2] was licensed under the PVPT system but did not fish in the EEZ. Since 1979, the MMA has also issued 27 research and training permits at a nominal fee to vessels from academic and research institutions.

Joint Ventures

Since 1979 the MMA has licensed three joint-venture arrangements with domestic companies in the FSM. The first, from 1983 to 1985, involved a Japanese group purse seine operation. The vessels had mechanical and crew problems and came under pressure from the Japanese Government to cease operations. The joint-venture was operating outside the Japanese regulatory system on group purse seiners which at that time allowed only seven units to operate in this area.

The second joint-venture was between the Yap Marine Development Venture and Monju Suisan Company Ltd. of Japan. The operation was given a 1-month research permit in February 1989 to drift gillnet for sharks and tuna. The venture suffered low catches and pressure from the Japanese Government to cease the operation. The MMA did not renew the permit in recognition of the global concern about drift netting.

The Caroline Fishing Company was founded in 1990 as a three-way joint-venture between the State of Pohnpei, the FSM National Fisheries Corporation, and an Australian fishing company to purchase and manage three small refurbished purse seiners. As a joint-venture arrangement, they are subject to a rebate on license fees.

The MMA remains supportive of joint-venture operations based in the FSM because of the opportunities they provide for employment and training. Before a joint-venture permit is granted each request is reviewed carefully to ensure that adequate benefits will accrue to the FSM economy.

Transshipment Development

Transshipment of sashimi grade tuna began in Micronesia in 1986 when small Japanese longliners landed their fish in Guam for airfreight shipment to Japan. This arrangement proved to be extremely lucrative, and the number of vessels involved grew quickly. At that time the Japanese Government did not regulate the activities of small tuna longliners, but there was an ordinance prohibiting landing and transshipment of tuna in foreign ports.

On 2 October 1989, the Japanese Government took action to control transshipment of tuna at foreign ports. Exploratory fishing licenses valid for 1 year were issued to small Japanese longliners allowing them to land tuna in Guam and Saipan only. By the end of October, 83 exploratory licenses had been issued, 63 to small longliners and 20 to larger longliners. The licenses were issued with strict reporting requirements (Anonymous, 1990b). Many of these vessels wished to fish in FSM waters and yet were not covered by the existing agreement between the MMA and the Japanese Fisheries Association (JFA) which only covered vessels based in Japan. Against great resistance from the JFA, the MMA established an agreement with the transshipment agents in Guam to allow the vessels to fish in the FSM EEZ. These vessels were subsequently incorporated into a single arrangement with the JFA on 1 March 1990 which also authorized some of the vessels to offload in FSM ports. The number of Japanese vessels transshipping in Micronesian ports is expected to increase with the further easing of Japanese Government restrictions. This should result in more vessels seeking access to FSM waters.

In 1990 about 70 Taiwanese longline vessels transshipped in Guam and about 60 in Palau. The number of Taiwanese vessels operating from these ports is also expected to increase.

[2] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Transshipment of purse seine catches has been carried out in Pohnpei, Chuuk, and Yap and will increase with the development of dedicated packing facilities and canneries planned for each state. The international pressure to end transshipment at sea may also result in increased purse seine offloading in FSM ports.

State of the Stocks

The first assessment of tuna stocks in FSM waters was carried out by the South Pacific Commission's Skipjack Survey and Assessment Programme (SSAP) between 1979 and 1981. The study showed that the stocks of skipjack tuna exploited by the surface fishery in the western Pacific were very large and only lightly exploited at that time. The SSAP also revealed that skipjack tuna were extremely mobile and could readily migrate between the EEZ's within the region (Kearney, 1983).

Interactions

Interactions may occur through the movement of fish between areas and their interception by other fleets, by conflict between gear types on a fishing ground or by the taking of fish before they become available to another fleet or gear.

The SSAP tagged and released 8,542 tuna during three visits to FSM waters between 1978 and 1980, and about 65% of the 297 fish recaptured were taken in FSM waters. As the remainder were taken in international waters or in the EEZ's of other countries, the SSAP demonstrated skipjack tuna fishery interactions at a subregional level. For the FSM, there appeared to be interactions with fisheries in the waters of the Commonwealth of the Northern Mariana Islands and the Republic of the Marshall Islands. Fish from the Marianas contributed moderately to the throughput of 17.4% in the FSM, while fish from the FSM contributed significantly to the throughput of 37.5% in the Marshalls.

Gear conflict between the pole-and-line and purse seine fisheries could be expected since both target surface tunas. The extent of direct conflict may, however, be small as pole-and-line vessels operate mostly in the northern portion of the EEZ, while purse seiners are concentrated in the south. Direct interaction is most likely in the area southeast of the Mortlocks and southwest of Chuuk where the fishing grounds for each gear type overlap.

In contrast, purse seine and longline fisheries are both widely distributed within the zone increasing the possibility of interactions through the interception of fish by surface gear before they become available to longlining. Yellowfin tuna are exploited by both fisheries, and the impact of purse seining on the longline catch of yellowfin tuna is of major concern. Based on logbook records, average yellowfin tuna catch rates in the zone have been relatively constant during the past 7 years in both the FSM and the region as a whole (Anonymous, 1991). The adoption of deep longlining by Japanese longliners targeting bigeye tuna, *Thunnus obesus*, has increased bigeye tuna catch rates throughout the FSM and the region. The relationship between surface schooling yellowfin tuna vulnerable to purse seining, and those yellowfin tuna inhabiting the mixed layer above the thermocline fished by regular and deep longline techniques is unclear. It appears that definitive analysis of interactions requires detailed study of both movement and growth.[3] The SPC Regional Tuna Tagging Project (RTTP), which began in 1990, is investigating interactions between domestic and foreign fisheries and may also provide information on stock structure and delineation.

Species Assessments

By 1989, considerable concern had been expressed at the prevailing and projected levels of exploitation of tuna stocks in FSM waters. In 1990, the MMA therefore reviewed available data in consultation with experts from FAO[4] and SPC (Hampton, 1991) and made a preliminary assessment of the status of the stocks of the major species. The assessment was considered necessary as the fisheries had changed markedly since the SSAP regional assessment of 1981.

Since the SSAP study, the pole-and-line fishery has declined, and the development of the purse seine fishery has significantly altered the extent and magnitude of effort in the surface fishery. The SSAP results must therefore be viewed within the context of the pole-and-line fishery then operating, and other data need to be incorporated for an up-to-date stock assessment. The primary data sources are the records of catch and effort provided by DWFN's under access agreements. The relationship between catch and effort is a useful indicator of stock condition, but raw catch per unit effort (CPUE) data should be interpreted cautiously as catch rates are affected by both oceanographic conditions and fishing practices.

Skipjack Tuna

The extent of the skipjack tuna resource vulnerable to the pole-and-line fishery in the FSM EEZ could not be determined from results of the SSAP study owing to insufficient data. Consequently, data for the FSM, Palau, the Marshall Islands, and Guam were aggregated, and the equilibrium standing stock of skipjack tuna vulnerable to the fisheries in the combined areas was estimated to be between 373,000 and 1,305,000 t. The turnover rate (due to natural mortality, fishing mortality, emigration, and growth out of the vulnerable size classes) was estimated to be 23% per month. Under normal conditions, this meant that between 103,000 and 252,000 t of skipjack tuna were moving through the combined area of the fishery each month. The harvest ratio (fraction of throughput harvested each month) was estimated at 2–4.8%. As a result, the pole-and-line fishery within its then geographic limits was considered capable of markedly increased catches without harming the skipjack tuna resources (Tuna Programme, 1984). The assessment of skipjack tuna in Micronesian waters

[3] Sibert, J. 1990. Tuna fisheries interaction and status of the stocks in Federated States of Micronesia. Food Agric. Organ., U.N., Rome, unpubl. rep., 27 p.

[4] Sibert, J. 1990. Interaction between tuna fisheries in Federated States of Micronesia. Food Agric. Organ., U.N., Rome, unpubl. rep., 8 p.

indicated a large resource with a standing stock of between 2,500,000 and 3,700,000 t (Kleiber et al., 1987). In 1989, the skipjack tuna catch by all fleets in the FSM was less than 15% of that.

Purse seine CPUE (Fig. 5) has been relatively constant since 1979. Pole-and-line CPUE (Fig. 5) is more variable, with an increasing trend since 1985 (the 1990 figures are incomplete). The CPUE figures for the surface fishery are indicative of a healthy stock, although it is possible that some reduction in abundance could have been offset by increases in fleet efficiency. It is therefore prudent to regard the interpretation of short-term trends in raw CPUE in the surface fishery as tentative.

The plot of skipjack tuna catch against effort (Fig. 6) shows a relatively linear relationship with catches remaining proportional to effort at high levels of effort. The lack of response of the stock to the highest levels of effort is indicative of less than full exploitation and supports the contention that the surface catch may be increased.

Yellowfin and Bigeye Tuna

Because the standing stocks of yellowfin and bigeye tuna were not estimated by the SSAP, stock assessment must rely on the interpretation of catch and effort data. Fortunately, there exists a long history of catch and effort data for the Japanese fishery since 1962. These show several long-term declines in yellowfin tuna CPUE, including one since 1978. This cannot convincingly be ascribed to the effects of purse seining since it was evident several years prior to the expansion of the purse seine fishery. A possible cause is the fishing down of the stock by longlining, although some later interaction effects with the purse seine fishery cannot be ruled out. Yellowfin tuna CPUE has stabilized since 1984, and bigeye tuna CPUE, which was relatively stable up to 1983, has gradually increased (Fig. 7).

The plots of catch against effort for yellowfin tuna (Fig. 8) and bigeye tuna (Fig. 9) show no indication of the classic dome-shaped production curve when effort reaches high levels. This is considered indicative of less than full exploitation.

While there is no direct evidence that purse seine catches of yellowfin tuna have contributed to a reduction in longline yellowfin tuna CPUE, it is possible that other changes such as spatial variations in distribution of longline effort may be masking interaction effects. Substantial changes have taken place in fishing methodology with increased targeting on bigeye tuna, and management of either species will affect the harvest of the other.

There are major deficiencies in knowledge of the biology of yellowfin and bigeye tunas which preclude conclusive stock analysis. The RTTP will provide much needed information on stock structure, migrations, growth, and interactions to allow better stock assessments to be made in the future. However, on the basis of present data, no stocks of tuna within the FSM appear to be overexploited.

Setting Harvest Levels

The preliminary stock assessment carried out in 1990 by FAO and SPC

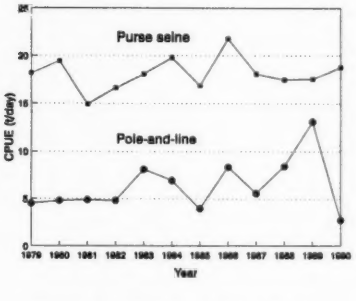

Figure 5.—Purse seine and pole-and-line catch per unit effort from 1979 to 1990.

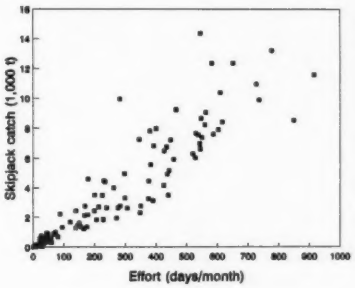

Figure 6.—Monthly skipjack tuna catch against effort for purse seiners from 1979 to 1990.

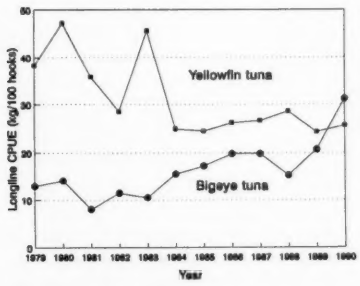

Figure 7.—Longline catch per unit effort for yellowfin and bigeye tuna from 1979 to 1990.

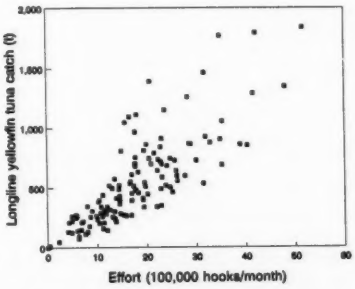

Figure 8.—Monthly yellowfin tuna catch against effort for longliners from 1979 to 1990.

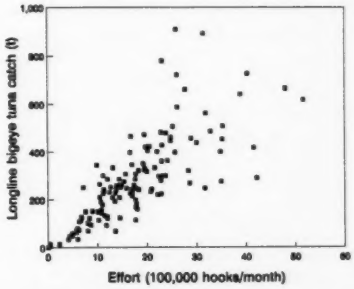

Figure 9.—Monthly bigeye tuna catch against effort for longliners from 1979 to 1990.

indicated that the stocks were in good condition and could support higher levels of exploitation. No stocks appeared overfished by the then prevailing levels of exploitation, and there was no compelling evidence to support reduction in effort in any fleet for the purpose of biological conservation. Despite this, the MMA considered it inadvisable to allow effort to continue to increase, dictated solely by the need for increased revenue. Therefore, a conservative management strategy was implemented, advocating modest increases in present catches. The recommended harvest levels were based on previous catches, taking into account changes that had occurred in the fishery, with the assumption that CPUE was maintainable at the then current levels. This approach requires accurate monitoring of the fishery and frequent assessment of the status of stocks to detect changes indicative of overfishing.

Harvests

The following harvest levels were suggested by FAO and endorsed by Hampton (1991). Historically the purse seine fishery has produced annual yields of 118,000 t of skipjack tuna. This level is considered sustainable at a CPUE of 14.0 t per vessel per day. About 25% of the purse seine catch shown in Figure 3 is yellowfin tuna, and that fishery is considered capable of producing 27,000 t of yellowfin tuna at a CPUE of 4.6 t per day.

The pole-and-line fishery has produced catches of up to 50,000 t per annum, and the present catch of about 15,000 t per annum is only a small fraction of the potential skipjack tuna yield. Thus, it should be possible to substantially increase catches without damaging the skipjack tuna stock. The pole-and-line catch could be increased to at least 32,000 t with an effort of 5,600 boat days at a CPUE of 5.7 t per day (the long-term average from 1972 to 1989).

In the past, the longline fishery has produced annual catches of 8,100 t of yellowfin tuna and 3,600 t of bigeye tuna. Harvest levels of 8,000 t of yellowfin tuna and 8,000 t of bigeye tuna with an annual applied effort of between 36 and 44 million hooks were considered reasonable by Sibert.[3,4] The wide effort range is due to the different expected hooking rates for yellowfin and bigeye tunas. The relatively large increase in the proportion of bigeye tuna demonstrates the ability of longliners to selectively target that species.

Although stocks appear sound, there are considerable uncertainties and limitations in the data. None of the fisheries have demonstrated significantly decreased catches at the highest recorded levels of effort, and the response of the fisheries to large increases in effort is therefore unknown. Large harvest increases should therefore be proposed only with great caution, although modest increases can be approached more confidently. Suggested harvests shown in Table 2 are based on previous harvests and assume that current CPUE levels are maintained despite increased effort.

Table 2.—Suggested tuna harvest levels (t).

	Harvest levels (t)			
Gear type	Yellowfin	Bigeye	Skipjack	Total
Longline	8,000	8,000		16,000
Purse seine	27,000		118,000	145,000
Pole-and-line			32,000	32,000
Total	35,000	8,000	150,000	193,000

The problem of increased yellowfin tuna catches by the purse seine fishery could become acute should the skipjack tuna catch increase markedly. If large skipjack tuna harvests become a primary management objective, careful consideration must be given to the impact of concomitant yellowfin tuna catches on longline fisheries.

Further Stock Assessments

Detailed and specific assessments of tuna fisheries in the western Pacific have been hampered by data deficiencies. The lack of high-seas data from DWFN's remains a problem and has precluded detailed stock assessment. The provision of high-seas data to complement regional logbooks has been identified as a priority by Pacific island nations and is urgently required, as are provisions for validating logbook data and verifying offloadings. International agreement, regional collaboration, and national support are essential to ensure the cooperation of DWFN's.

Powerful new analytical models are required to interpret the complex fishery dynamics presented by the diverse gear types and flags operating in the region. This is the role of regional organizations, and national and international efforts must be intensified to ensure that methodologies are available for accurate and timely stock assessment. Basic biological data are also necessary. Size frequencies, growth estimates, and age-selective mortality estimates are necessary for more detailed models which will improve stock assessments and estimates of the optimum harvest levels.

To this end, the MMA has developed an active fisheries observer program which, with the establishment of a port sampling program, has provided the first detailed description of the catch. Enhancing the quality and coverage of catch and effort data is also a major goal. The MMA recognizes that, although proper stock assessment is a regional task, each country must ensure the collection of basic data.

The Future

Initially, the MMA strived to gain recognition of jurisdiction over resources of the 200-mile zone. Attention was then focused on achieving appropriate returns for access from license fees. While access and fee level negotiations continue, the MMA has increased efforts to assess the status of resources and to ensure a rational approach to setting harvest levels.

With the evidence of interactions provided by the SSAP, it is obvious that management of stocks cannot be undertaken unilaterally. Restrictions on catch and effort will only be effective if implemented on a regional basis. This will require considerable accord between countries of the region and the possible compromise of national fisheries development aspirations.

U.S. funding to the FSM Government under the Compact of Free Association will cease by the year 2002, resulting in increased pressure to maximize revenue from all sources, includ-

ing fisheries. It appears unlikely that domestic fisheries will be sufficiently developed to replace foreign fleets by that time, and thus, fishing access fee revenue will increase in importance. While large increases in the skipjack tuna catch are no doubt possible, some compromise on yellowfin tuna harvests will have to be made. At present there is too little known about the stock structure, fisheries interactions, and population dynamics of yellowfin tuna to be able to propose optimum yields. The RTTP, currently being carried out, will provide better estimates of the size and movements of yellowfin and bigeye tuna stocks and allow more realistic modelling of those populations.

In the future, the MMA will also assume responsibility for monitoring domestic fishing vessels. To effectively manage the fishery resources of the EEZ, the total catch must be monitored. That means all vessels, foreign or domestic, will be required to report their catch and effort within the EEZ.

The MMA has encouraged transshipment in FSM ports by discounting license fees for participating vessels. However, the activities of longline vessels transshipping in FSM ports are severely limited by availability of air freight space, and operations will remain restricted until dedicated freight flights are secured.

In Pohnpei, a fish processing plant is presently being constructed by Pohnpei State's Economic Development Authority, and the National Fisheries Corporation is planning a tuna cannery. In Chuuk State, a longline transshipment base with wharf, coldstore, and processing facilities is being built, and a similar development is planned for Yap State. Major tuna handling and processing facilities are also planned for Kosrae State. While expanding FSM's involvement in tuna fisheries, these domestic fisheries will also provide unprecedented opportunities for biological sampling and stock monitoring.

In view of the major increase in purse seine catch and the possible effects on resources, the MMA is focusing on active management of the resources. This approach allows controlled increases in effort while closely monitoring catch and CPUE.

Regional and international initiatives on cooperative management will also be boosted. At the same time the MMA will continue to seek higher returns from the resources, including benefits additional to access fee payments. In particular, FSM involvement in the exploitation of the resources in the form of joint-venture arrangements and basing of foreign vessel operations in the FSM will be encouraged.

In the long term, joint-venture and later domestic vessels will replace foreign vessels operating in the EEZ. Until then, the MMA will continue to maximize revenue and encourage development of domestic fisheries while ensuring that stocks are maintained.

Acknowledgments

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Background Concepts for a Rotating Harvesting Strategy with Particular Reference to the Mediterranean Red Coral, *Corallium rubrum*

J. F. CADDY

Introduction

Developing a quantitative model for an exploited population which reflects its main demographic features is now a standard precondition for drawing up a management plan for the resource. It can also reveal the most important questions to be addressed by a research program in support of management.

Red coral, *Corallium rubrum*, is widely distributed throughout the Mediterranean Sea, and, at least in the past, it has occurred in commercially exploitable concentrations off Spain, Algeria, and Sardinia, as well as being widely distributed at lower densities from the Aegean Sea and the southern and eastern Mediterranean to the Sea of Alboran inside the Straits of Gibraltar. Preoccupation has been expressed by fishermen and industry with the declining returns to an ever more sophisticated harvest sector, which has progressively exchanged primitive dragging equipment (the Saint Andrews Cross) for mixed gas diving equipment capable of operating at over 100 m depth. These concerns led to two expert Consultations (GFCM, 1984; GFCM, 1989a) where the options for future management were discussed by the industry and scientists. At the second of these, the main elements of the rotating harvest scheme presented here (Caddy, 1989) were seen as a useful basis for further discussion, and were further refined in a meeting held in Algeria on 9-11 January 1989 (GFCM, 1989b: App. E).

This paper provides a summary of the underlying considerations, not only because of their interest in the case of management of red coral resources, but for possible wider application to other sedentary or territorial resources.

Developing a population model for precious coral resources, as for any approach to fishery modelling, has to take into account the fact that population parameters are not precisely known; nor is the size of the population, the rates of recruitment and growth, or the death rates due to natural causes and fishing. It is necessary to base our models, and the resulting management regimes, on the best information available.

Alternative Approaches to Modelling Coral Populations

The first General Fisheries Council for the Mediterranean (GFCM) Technical Consultation on red coral resources of the western Mediterranean (GFCM, 1984) discussed the question of modelling red coral resources and examined the application of three types of models proposed by Garcia (1984) in the same report. These were: 1) Models that assume a mining strategy, 2) generalized production models, and 3) structural or yield-per-recruit models. The first appears relevant to short time and distance scales and describes well the strategy of fishing, especially with divers, over an individual patch of red coral.

The second modelling approach poses significant problems in terms of the definition of fishing effort, given a local availability which changes with depth, currents, bottom configuration, and distance from port (although locality-specific production models have been postulated, e.g. Caddy and Garcia, 1983). Together with the third type, simple production models depend on a dynamic pool assumption for the mixing of age groups between successive

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ABSTRACT—A simple cohort model was used as the basis for selecting the appropriate periodicity and number of separate unit areas in a rotating harvest scheme for a sedentary species, the red coral, Corallium rubrum, *in the General Fisheries Management Council for the Mediterranean area. The rotation period in years, and hence the minimum number of unit areas involved, was determined on the basis of the time to maximum biomass by a simple calculation of the yield-per-recruit type, requiring a knowledge of natural mortality and growth rates. Other criteria may be more important, however, and in general for a long-lived species, will result in shorter rotation periods. These criteria may include economic factors, criteria based on the preferred size or quality of product, or criteria that take into account the cumulative risk of illegal fishing of closed areas with time, hence the growing cost of enforcement as harvestable product accumulates. For red coral, although maximum biomass is predicted to be reached after some 15-44 years, the above considerations suggest that a rotation period of some 9-15 years would be close to optimal, taking into account a range of the above considerations. This article discusses the relative merits of rotating harvest schemes in contrast to quota management for sedentary and semi-sedentary resources or geographically isolated substocks of a mobile resource, and concludes that this approach may have considerable potential as an alternative approach to resource management.*

harvests. This last assumption does not accommodate well to a harvesting model that reflects the geographical dispersal of a sedentary resource on a Mediterranean-wide basis, where the mean age of the local population often reflects the time since last harvest.

In recognition of this, the first Consultation recommended that "the principle of rotations, zones opened to fishing and then closed for set periods, must be carefully studied." It was further noted that several countries and regions already had closures of coral fisheries in their fisheries legislation; notably, a 5-year closure established for coral fisheries in Sardinia and a 25-year closure provided for in Spanish legislation. A 9-year rotating closure period was apparently also practiced by Arab fishermen in the 10th Century (Grigg, 1988).

Four aspects of modelling a red coral population emerge from the biology of this organism in which it differs significantly from, for example, the more commonly modelled finfish populations, namely:

1) Populations are sedentary, and their density varies from place to place.

2) Because they are sedentary, the effects of past local harvesting remain local, at least until the population regenerates itself. In other words, the dynamic pool assumption must be rejected (Caddy, 1975).

3) Like other high-value sedentary or semisedentary organisms, harvesting (especially by scuba) tends to be in a 'pulse' fishing mode, in which local patches are cleaned out selectively, leaving only inaccessible or noncommercial individuals, before another patch is located and harvested in turn.

4) Growth of corals, and hence regeneration of exploited populations, is very slow, and as such, harvested areas are effectively removed from production for a significant period. Periods of up to 50 years have been mentioned as recovery times in Pacific fisheries (Grigg 1984).

5) However, closure of a coral fishery for such a length of time imposes unacceptable surveillance costs and leads to an increasing incentive for illegal fishing (Garcia, 1984).

Appropriate Population Models for a Precious Coral Resource

Yield per Recruit Models

The yield model used in a particular fishery should ideally reflect the likely management regime in order to facilitate its application in practice. In this sense, the dynamic pool yield-per-recruit models are not particularly well adapted to a sedentary species, unless the spatial nature of the resource is taken into account (e.g. Caddy, 1975; Gales and Caddy, 1975; Sluczanowsky, 1983). They may be useful, however, for a first treatment of an open-access resource in which we wish to know the effects of a minimum size limit and a particular level of fishing effort on the resource. Such models have been applied to precious corals by Garcia (1984) and Grigg (1984). The beginnings of a bionomic framework for population modelling based on a method of age reading of colonies have been provided for the Mediterranean red coral resources by Garcia-Rodriguez and Masso (1986a,b).

It was clear at the first GFCM workshop, however, that continuous harvesting in a sustainable way (i.e., without depleting the resource) would necessitate very low levels of annual harvest with respect to the stock size, if populations were not to be depleted. A range of estimates has been made, starting with 1.3% for Masso et al. (1986a), Grigg (1984), who mentions values of 3.5% of the stock size harvested annually as corresponding to MSY, and figures of the order of 5% in Garcia (1984). In terms of rotational harvesting, these are equivalent to dividing the stock range into roughly 73, 28-29, or 20 unit areas, respectively, and harvesting one of them completely each year. This is precisely the conceptual framework that is adopted in this paper, although it is developed from a rather different set of assumptions.

Rotating Harvest Models

The most obvious alternative management scheme to an open-access fishery for sedentary species is one where the stock is divided into subareas, whose harvesting is staggered over a period of years, thus allowing depleted stocks to recover before reharvesting. The main purpose of this paper is to explore the simplest type of model that might be developed to underlie such a management regime and how, in particular, the number of unit areas would be defined, and hence the proportion of the total biomass harvested annually. With this scheme it is assumed that the commercially valuable animals in a given unit area are all harvested (with the exception, of course, of those individuals that are not accessible in crevices, deep water, etc., which would still contribute to recruitment, and those small individuals which it is uneconomic to harvest).

Rotating harvest regimes for sedentary organisms can be represented using yield-per-recruit (*Y/R*) models with spatial components (Caddy, 1975), but these require considerable information on population parameters, which are not yet available for red coral resources. It appears, however, that the framework for this type of model can be considerably simplified for sedentary species to allow different treatments to be elaborated for geographically different subsections of the stock. The objective of this modelling and management framework is to allow harvesting strategies to be expressed in terms of the time intervals since the resource was last harvested. Implicit in this approach is the concept that evolution of the cohort biomass may be followed throughout its life history to the point at which optimal conditions for harvest are realized (Alverson and Carney, 1975).

If we take the whole population spread over an area A and divide it into n subareas which contain roughly the same fraction of the stock size or potential yield, then each of these has to support the entire fleet over a single annual season without complete closure of the whole fishery in any one year. Suppose, then, that a recovery period of y years is needed after harvest to return the stock to the optimal conditions for reharvest; then the minimum number of unit areas will be $n = y+1$ areas including the harvest year, when it is assumed, pessimistically, that

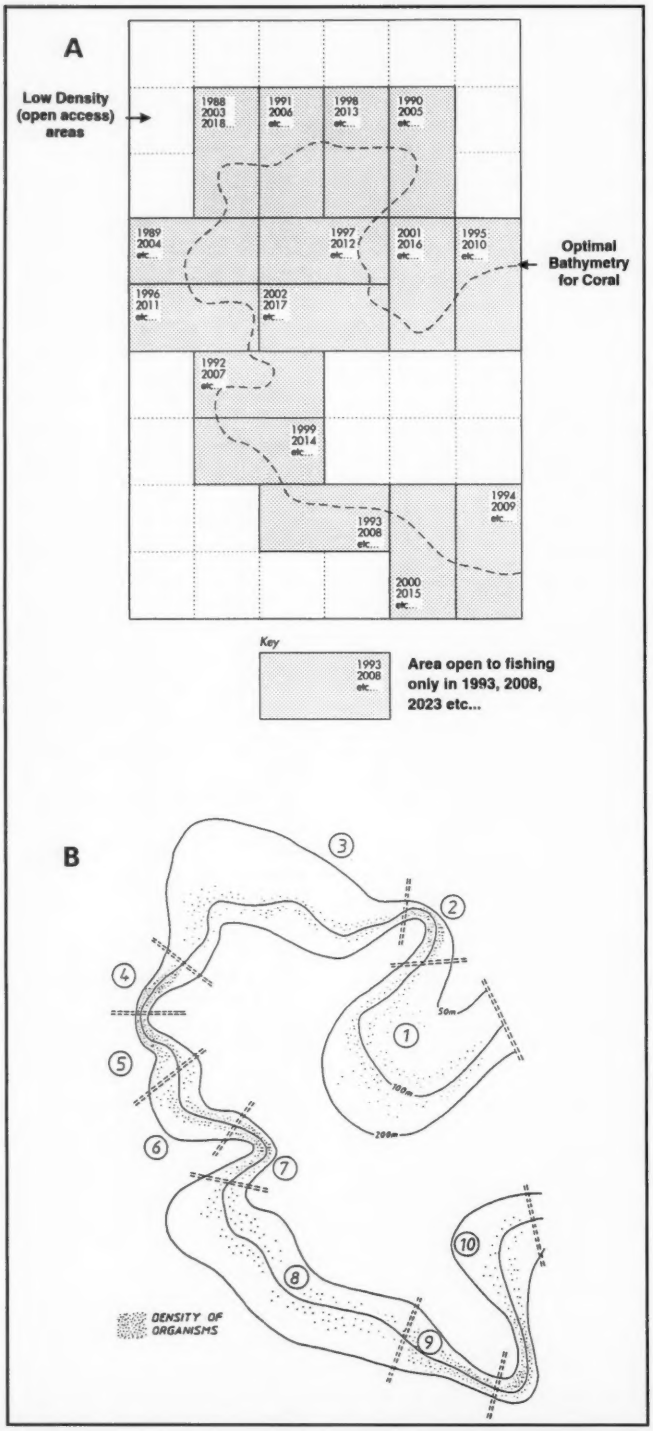


Figure 1—A: Hypothetical rotating harvest scheme with 15-year period, beginning in 1988, and a cycle that repeats in 2003, 2018, etc. Only areas of known productivity are included; other areas are assumed to remain "open access" or to be permanently closed (reserves). B: Rotating harvest scheme in which the boundaries of each area are designed to produce roughly the same potential yield.

no significant recruitment survives locally (i.e., that settlement season precedes harvest). Figure 1A shows one hypothetical rotating closure scheme where, for simplicity, 15 unit areas have been defined of equal size. As noted above, it might be more appropriate to maintain the fraction of the stock size in each area constant, rather than the extent of the areas themselves, as in the alternative approach illustrated in Figure 1B.

Of course, some fraction (B') of the total biomass (B) could be excluded from the rotation scheme, or two or more unit areas could be opened simultaneously to harvesting. The first eventuality could include areas of fringe population excluded from the rotation scheme and left open to harvesting full time. Alternatively, some areas where reproduction occurs more regularly (Caddy, 1988) could be closed indefinitely as "mother lodes" or stock conservation areas. All of these options would reduce the fraction of stock size in any particular unit area, since, given a biomass of B tons in the whole area set aside for rotational closure, only $(B - B')/n$ tons would be available for harvest annually from any unit area open that year.

Take a concrete example, where we suppose that $y = 25$ years, and the hypothetical biomass available to harvesting is $B = 500$ metric tons (t). The minimum number of unit areas is then 26, and the population harvestable annually should then average around 19 t. It can be seen that this approach is, in practice, equivalent to setting an annual quota, without the disadvantage of having to define the level of catch in advance. Some other advantages and disadvantages of this approach, when compared to the principal alternative management approach, namely a quota scheme, are described later in the pa-

per. In the next section, an attempt will be made to formulate a simple model and define the number of unit areas needed in such a scheme.

Population Parameters

Although population parameter values are not precisely known for Mediterranean coral stocks, they are likely to show wide variation from place to place, and a population simulation is still useful in revealing the implications of a range of values that seems likely to encompass the actual parameter values that apply for the stock.

With respect to natural mortality rates, Grigg (1984) suggests a range of values for M = 0.04 - 0.07, which is equivalent to mean ages in a virgin stock of 25+ to 14+ years assuming an age at first harvest of 3+ years.

Growth in length is usually given in terms of millimeter increments per year, but presumably growth slows down for older colonies, so some growth function (i.e., von Bertalanffy) will be needed that shows this characteristic, especially for expressing growth in weight. In developing an idea of the range of values for the von Bertalanffy parameters that would be appropriate for such a long-lived, slow growing organism, it is assumed that by, say, 50 years of age, 90% of the potential growth in length has been accomplished. If we set $t(0) = 0$, it is possible to then estimate an equivalent value of K without knowing the maximum length, L_∞ from:

$$0.9 * L_\infty = L_\infty * (1 - \exp - (50 * K)).$$

This allows elimination of L_∞ from the equation, and a solution for K of approximately $K = 0.05$.

If growth in weight is assumed isometric and the value adopted for asymptotic weight of 1 kg by Garcia (1984) is used, then the growth in weight with age is given by:

$$W(t) = 1{,}000 * (1 - \exp - (Kt)) ** 3,$$

and values for weight at age for K = 0.05 can be generated.

Another approach was adopted by the 1989 ad hoc working group on rotating harvest (GFCM, 1989b) by fitting the von Bertalanffy equation for isometric growth in weight to weight-at-age data tabulated by Garcia-Rodriguez and Masso (1986a, b). A best-fit with constraint W_∞ = 1,000 g gave a value of K = 0.035. Although weights progressively exceed von Bertalanffy expectation after age 35, this was not felt to be relevant for shorter rotation periods.

Cohort Biomass

Given that the number of individuals from an unfished cohort (assumed initially at 10,000 individuals on recruitment) drops off with time according to

$$N(t) = N(t-1) * \exp(-M),$$

the cohort biomass (largely consisting of skeletal material) is then

$$B(t) = N(t) * W(t).$$

It is now possible to calculate biomass at age for a range of values of K and M, and to observe when the biomass is maximal, which occurs when the increase due to growth is compensated for by the loss due to natural deaths. This is then the age at which harvesting the cohort would give the maximum yield. In the case of natural stocks, this is of course impossible to achieve since there is a mixture of age classes which are mostly harvested together. The rotating harvest regime potentially comes closer to this "ideal" strategy than other methodologies, since after at least one rotation of all areas has been completed, the older age groups (with ages less than or equal to the closure duration) have presumably been protected from harvest and should dominate the catch by weight, unlike the situation with open access where, under heavy fishing, the fishery comes to depend heavily on young animals.

Values for the age at maximum biomass t_{max} are given in Table 2 for a range of values of M and K, together with the predicted time interval for maximum annual biomass increment, and the number of whole years before a range of percentage increases in biomass are predicted to be attained.

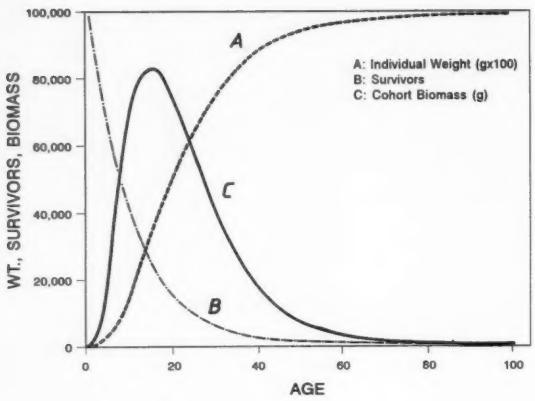
As expected, the time elapsed before maximum biomass is attained increases as K and M decline, as does the time elapsed before the other criteria mentioned above are realized. Trajectories for growth, mortality, and biomass are given in Figure 2 for two sets of trial values. Figure 3 compares the same biomass trajectory with both the annual increment in biomass with age and the percentage annual biomass increase.

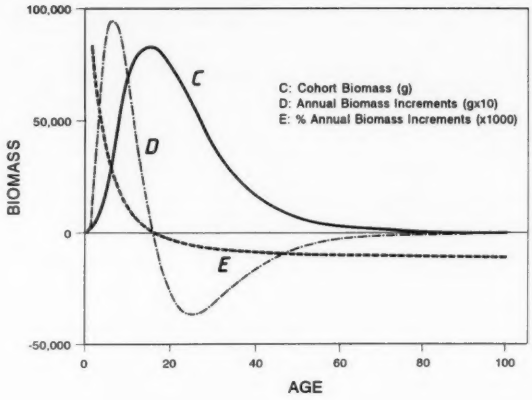
Discussion

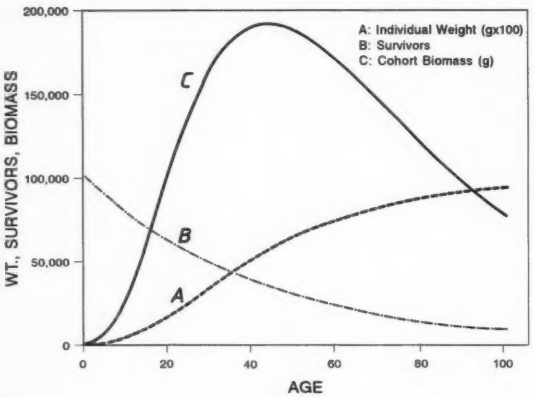
Modelling Theory

Harvests of "wild" marine resources, because they take a mixture of age classes, are usually managed (if managed at all) by means of an overall limit on the catch and/or fishing effort and by the imposition of a minimum size limit, and they are considered to be subject to continuous fishing pressure by the harvesting fleet. Occasionally, closed seasons/areas are used to supplement these measures, but for marine fish stocks, because a degree of dispersal between areas occurs, the option to subdivide the stock into different subareas does not usually exist, except where specific nursery or spawning areas may be protected (e.g. by seasonal closures).

Therefore, in finfish yield calculations, the whole stock is considered to form a dynamic pool; all members of an age group above a given age of first capture being considered as having an equal probability of harvesting at a given time. In the case of sedentary populations, harvesting subunits of the population separately is possible, using concessions, leases, or areas of open access, so that the dynamic pool assumption is only reasonable at the unit area level. Schemes of harvest, such as the rotational harvest scheme described here, then become advantageous to consider, and, as it proves, relatively easy to visualize in the form of a simple model. Although simulation is no substitute for experience in field application, this type of measure appears to be comparable to optimally managed open-access regimes with respect to the potential yield realizable, and may have advantages with respect to survival of under-sized discards and in economic terms.







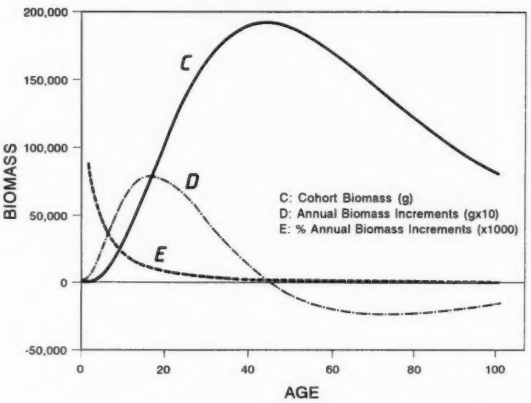


Figure 2—Trajectories of growth in weight (A), decline in numbers (B), and cohort biomass (C) with age, for (lower) $M = 0.01$, $W_\infty = 1{,}000$ g, $K = 0.08$; and for (upper) $M = 0.025$, $W_\infty = 1{,}000$ g, $K = 0.04$.

Figure 3.—Trajectories of the cohort biomass C shown for the two runs in Figure 2, compared with the annual biomass increment for the population D, and the percent annual increase in biomass E.

Future developments of the single cohort model could of course be envisaged which incorporate more than one age group simultaneously, and this may change somewhat the calculated age to optimal harvest predicted by this simple model. It seems, however, that for a variety of sedentary species, this effect may not be considerable, at least for long-lived sedentary species. Two factors (GFCM, 1989b) may be counterbalancing in the case of red coral and are not taken into account in this simple approach:

1) The work of Garcia-Rodriguez and Masso (1986a, b) confirms that red coral, like many other sessile benthic organisms (e.g. Hancock, 1973, 1979), show intraspecific competition which limits recruitment of new year classes of a sedentary invertebrate once one or several year classes dominate the substrate. These Spanish results suggest that after 3 years, recruitment to previously harvested surfaces is progressively saturated.

2) With careful harvesting, the age 2-3 colonies may largely survive to the next harvest cycle.

It will require practical experience in each case to determine which of items 1) and 2) are most important in each case, so that, for the present, there are not adequate data on density dependent recruitment to merit expanding the single cohort model. Clearly, more complex models may be developed that take into account density-dependent, or area-specific recruitment, growth, and mortality, as well as possible effects of "thinning" at some intermediate stage prior to completion of the rotation cycle. All of these aspects will require much more data to be implemented, in a situation where determining the exact optimum rotation period is less important than immediately implementing a management scheme based on a reasonable compromise for the periodicity, in which all important factors are given some weight.

The Need for Effort Control

One feature that red coral fisheries must share with fisheries for other valuable sedentary or semisedentary resources such as the abalone *Haliotis* sp., or lobsters, is that given the high unit value of the resource and the open-access nature of most fisheries, an excess of effort is inevitable in the absence of strict controls of fleet size and fishing effort. Some control of the number of entrants to the fishery is supposed, and is essential to the success of management by rotating closure. There are considerable difficulties in achieving limited license schemes, but these have the advantage that those fishermen licensed in the fishery have an incentive to protect the resource from infringements to fisheries regulations. Here we may perhaps consider also some of the practical problems facing such a management scheme by rotating harvest by comparing it with the usual quota management approach.

Rotating Harvest Schemes vs. quotas?

As we have seen, both of these management approaches aim to remove a sustainable yield from the population each year. From a yield/recruit perspective, rotating harvest schemes have the potential to provide a similar physical yield to open-access fisheries and a still higher economic yield, given that the rotation period could be adjusted to provide high proportions of those size groups commanding the highest unit price. If individuals of a given age are more valuable per-unit-weight, this should increase still more the total catch value. The spawning potential of the stock should also be greater with this management format, especially if one or more local "mother lodes" are maintained in unfished sanctuaries. Rotating harvest systems should allow significant numbers of spawners to accumulate, always assuming of course that the rotation period exceeds the age at maturity, and that some individuals, at least in adjacent areas, remain to contribute to the spawning stock in their own and adjacent areas.

From the perspective of fisheries control and surveillance, the advantages are not all one way, and both methods of management set exacting criteria for the management authority. For simple quota schemes, the need to control landings in port will have to be supplemented by some sea patrols to ensure that unauthorized fishing units are not operating once the grounds are closed or are not transshipping the catch at sea.

There will also be the need for control of fishing operations at sea with a rotating harvest scheme, to ensure that fishing is not occurring in unauthorized areas; also, a more precise control of the location of fishing will be needed. This is now feasible from a technical perspective, given that accurate position-fixing aids are now common on fishing vessels. There appear at first sight to be major problems for fisheries surveillance, which will increase progressively as the biomass on the grounds builds up. However, any vessel operating over a closed area with fishing/diving gear in operational mode, could be liable to penalties. Since, as for quota schemes, the authorized catch will be only a small proportion of the total biomass or standing stock, it is likely that with a rotational closure, the fishery will only need to operate for a small part of the year. Unlike quota schemes, however, there will not be the need for real-time gathering of catch information to ensure that the quota is not exceeded before the fishery is closed, although surveillance to detect landings of sublegal sizes, given some minimum size limit, may be desirable.

Criteria for Setting Time Periods for Rotating Closures

Given the general lack of commentary on this point in the classical population dynamics literature, one might deduce that the appropriate management criterion for harvesting a long-lived resource is the same as for a short-lived resource, namely, the realization of some optimal yield, whether expressed in economic or physical terms. It is clear, however, and has been expressed in various places, that controlling a fishery to achieve maximal yield where only a small proportion of the yield can be removed annually, imposes major problems and costs. This is especially true if the stock is long-lived and slow growing, and does not accumulate an annual increase in value which is at least equal to that considered a desirable rate of return to industry; notably, at least 10%. Hilborn and Walters (1992) noted that for unproductive stocks, such as the large whales, population growth rates of much less than 10%, from strictly economic considerations, leave little incentive to avoid the "mining" strategy described earlier, in which a large part of the stock is removed before scarcity reduces the incentive to harvest. This type of consideration must be taken into account in deciding on some alternative management strategy to "mining," which, although possibly suboptimal from the point of view of the yield it provides, would still be preferable to an open-access harvest, especially where surplus fishing effort exists beyond that needed to take the small amount of annual yield which is sustainable.

A similar perspective is outlined in Garcia (1984) with respect to coral harvests. The incentive for illegal fishing in a closed area, and hence the need for expenditure on surveillance, will go up steadily as the red coral colonies in a closed area increase in size and value. Garcia (1984) pointed out several considerations (Fig. 4) from the perspective of enforcement of rotational closures:

1) An open season will consist of two periods: An initial "useful" period when the value of daily catches exceeds the cost of fishing and a second economically wasteful period when they do not.

2) Given that fishing will be recognized to be economically unproductive immediately following closure, if penalties for infringement are significant, there will be less incentive for illegal fishing in just-closed areas; hence, surveillance can be less intense in these areas immediately following closure.

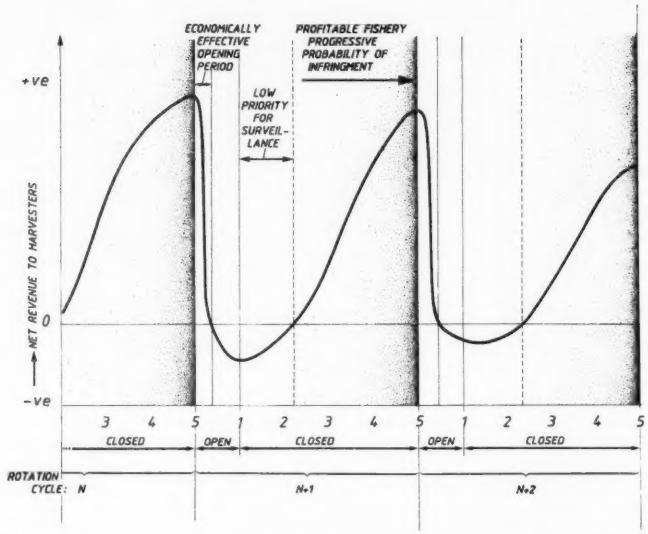


Figure 4.—Some of the features of a rotating harvest scheme (here, with a rotation period of 5 years), are shown from the perspective of control and surveillance of fishermen's adherence to the rotating closure (redrawn from Garcia, 1984).

3) The incentive for illegal fishing, and hence the need for surveillance, will increase the longer the fishery is closed, and particularly as the time of opening of a new area approaches.

Changes in Unit Value of Coral with Age

Unit value of coral depends on a range of considerations, including quality, size, and color or origin, of which colony size is of particular interest in terms of a rotating harvest scheme (Table 2). The unit value of colonies is higher for older colonies, but this is conditioned by the fact that a significant proportion of very old colonies are more likely to be of poor quality due to boring sponge, and here wastage may be higher. Small colonies with limb diameters of 6-8 mm command the lowest price per unit weight. Colonies of intermediate size are easier to process, and they provide a greater rate of return on the number of colonies harvested than very large colonies. These unit prices (Table 1), however, reflect the current size range available in the market, and it can only be speculated how relative prices might change if colonies of intermediate size dominated the market. Despite this, these data tend to reinforce the conclusion of this simple simulation that a rotation period of intermediate duration would be more favorable in terms of the type of coral available to the industry than one providing predominantly small or large colonies.

The several considerations above seem to provide a strong incentive to modify the initial "optimal" criterion considered in this paper, namely for a rotating closure designed to achieve maximum cohort biomass, which requires closures from 15 to 44 years, and replace these unrealistic "ideal" periods with shorter "suboptimal" periods calculated as in Table 1. Given these considerations, two other criteria may be suggested which give shorter rotation periods and lower yield, but would probably be more efficient and easier to enforce:

1) The time to maximum biomass increment: This is achieved after somewhat less than half of the time needed to achieve the maximum biomass.

2) With somewhat more validity from an economic perspective, one might consider setting a closure duration such that the advantages of closing the area for 1 year more would cause the percent annual increment in biomass/net revenue from leaving the resource on the ground to fall below some preset discount rate that would be at least equalled if the stock in the unit area were harvested in the current

Table 1—Results of simulations with the simple single-cohort model.

K	M	t	Biomass per 1,000 recruits (g)	Years to max. biomass increment	No. of Years to percent increment of: 50%	40%	30%	20%	10%
	0.025	44	19,871	17	5	6	8	10	16
0.04	0.05	39	80,089	13	4	5	7	9	15
	0.10	20	24,975	9	4	5	8	8	12
	0.025	35	288,551	13	4	5	7	9	14
0.06	0.05	25	141,218	10	4	5	7	9	13
	0.10	17	52,779	7	4	5	6	8	11
	0.025	30	364,110	11	4	5	7	9	13
0.08	0.05	22	198,815	9	4	5	6	8	12
	0.10	15	84,151	7	4	5	6	7	10

year. These percentages may then represent the added benefits to the industry of leaving the coral on the ground, as opposed to harvesting it and realizing an immediate economic gain. Table 1 seems to provide the basis for such a decision-making process.

The Size of Unit Areas

The size of the unit areas and their sequence of opening has obvious implications for the status of the resource and for fishery management, especially at the international level. Three considerations may be mentioned:

1) If unit areas are too large, recruitment from adjacent areas to a newly depleted zone may possibly be reduced, and stock regeneration will be more dependent on those individuals within the area which escaped harvest. (Sexual maturity is reported at ages 1-2 years for red coral so that, in theory at least, undersized individuals could contribute to population replenishment.)

2) The adverse local economic impact of protracted closure would be increased if closures are rotated always between closely adjacent areas, instead of as far as possible between different jurisdictions which are widely separated geographically.

3) In situations where multiple factors need to be resolved in deciding on the optimal rotation period, we may conclude that it may be more important to decide on and implement a rotation scheme that meets with the approval of all concerned, than to search for the "optima optimorum" for the period of rotation.

Table 2—Indicative information on prices paid in 1989 for coral comparable quality for different size ranges. Source: B. Liverino, expert in red coral industry, Torre del Greco, Italy; personal commun. in GFCM (1989b.)

	Price in Italian lire per kilogram (% purchased) by locality	
Category	Sardinia, Corsica, Yugoslavia, Palma de Mallorca, French coast (except Marseilles)	Marseilles, Costa Brava
Small, basal diam. 5 mm	100,000 (35%)	100,000 (55%)
Medium, basal diam. 8 mm	350,000 (40%)	280,000 (35%)
Large, basal diam. 11 mm	800,000 (20%)	770,000 (10%)
Extra large diam. >11 mm	1,300,000 (5%)	

Other Management Measures

Several ancillary measures that may improve the effectiveness of rotating harvest schemes were mentioned in GFCM (1989b), and they may be summarized as follows:

1) Measures should be taken to reduce harvest and incidental damage to small, unharvestable colonies.

2) Accredited coral fishermen should purchase a license for coral fishing, validated for the open area in question.

3) Individual landings should be in sealed bags, identified as to time and place fished, and registered on a duplicated tag or purchase record, with copies for the fisherman and buyer.

4) Penalties should be imposed for nonlicensed fishermen and those in possession (buyers or fishermen) of unworked coral without appropriate documentation.

5) Given that catch rates will fall rapidly after onset of the open season, a Leslie-Delury approach may be used during the open season in a monitored fishery that ensures that when mean catch rates fall below levels that are below the economic breakeven point (say, a daily average of <1.5-2 kg/day over a 2-week period (GFCM, 1989)), the season is closed early.

One potential advantage for enforcement offered by the Mediterranean red coral fishery is the existence of a well coordinated processing sector. This can largely determine the level of success of a management scheme with a controlled market. By purchasing material only at a centralized market, from licensed fishermen working in authorized areas, the buyers can help ensure that the incentive for harvesting outside these legally open areas is greatly reduced.

The Scope for Application of Rotating Closures

We may consider other situations or species in which rotating harvest schemes may find an application. The first of these is, of course, a nonmigratory behavior or reduced mixing between adjacent unit areas, where the annual diffusion rate E of the species from a unit area over the period of rotation n is such that $nE << F$, the instantaneous mortality rate exerted on the local population during the harvest in the nth year of the rotation. Situations where this may apply, apart from the obvious case of sedentary or semisedentary species (e.g. many shellfish), also include cases where a mobile species is effectively divided into subunits as adults, e.g. fish stocks of islands in an archipelago or in a series of lagoons or lakes, or even the fish populations of individual coral reefs where a degree of population isolation exists as adults. Two other advantages of this management methodology may be that 1) genetic selection against fast-growing strains, which is an inevitable long-term consequence of continuous harvesting with size-selective gear, is likely to be attenuated, and 2) the transition away from open-access regimes to some form of area-leasing arrangement, is facilitated.

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Submersible Observations on Lingcod, *Ophiodon elongatus*, Nesting Below 30 m off Sitka, Alaska

VICTORIA M. O'CONNELL

Introduction

Lingcod, *Ophiodon elongatus*, is an important sport and commercial species throughout the northeast Pacific and is the target of a developing troll fishery in southeast Alaska. Male lingcod are nest-guarders and are especially susceptible to harvest during the nest-guarding period. The Alaska Department of Fish and Game has protected some shallow-water spawning grounds, but the extent of spawning below 30 m is unknown.

Lingcod are lithophils (Balon, 1975); nest sites are usually in cracks or crevices in rocky habitat, often in areas of high current (Cass et al., 1990). Nests are reported in shallow water, generally < 36 m (Low and Beamish, 1978; LaRiviere et al., 1981; Bargmann, 1982), and Jewell (1968) noted a greater density of nests in shallow water. Cass et al. (1990) reported that spawning occurs in British Columbia and Washington in nearshore areas with high current. Previously, anecdotal information suggested nests occur in deeper waters. Miller and Geibel (1973) and Cass et al. (1990) proposed that nests occur in deep water because ripe males were caught on hook-and-line gear in waters deeper than 30 m. The occurrence of ripe males does not confirm the presence of nests, however. Males enter spawning condition before females do, and not all mature males successfully defend a territory and spawn.

Male lingcod move into shallow water and begin defending territories prior to spawning, whereas females migrate into the area to spawn and then return to deeper waters (Cass et al., 1990). Ova are deposited and fertilized in layers. Once spawned, the eggs are sticky, adhering to each other and the rock substrate. Individual ova are 3.5 mm in diameter; the entire egg mass may be from 3 to 65 l in size (Cass et al., 1990). The male guards the nest from predation by fishes and invertebrates throughout the incubation period which lasts about 7 weeks (Cass et al., 1990). Miller and Geibel (1973) found that the nest-guarding period lasts through March in California, whereas in British Columbia the majority of eggs hatch by mid-April (Low and Beamish, 1978). Later hatching is reported in areas of lower currents (Giorgi[1]).

Male lingcod are territorial throughout the nest-guarding period. This behavior makes them extremely susceptible to harvest, and once males are removed from the nest, the nest is usually lost to predation (Low and Beamish, 1978). This, in turn, can cause overharvest of local stocks because adult movement is limited and their reproductive mode does not promote geographic dispersal of young (Cass et al., 1990).

To protect nest-guarding males from harvest, the Alaska Board of Fisheries recently (1991) enacted a regulation for a winter-spring closure of commercial fishing for lingcod inside a line running along the outer coast of southeast Alaska. This line, termed the "surf line," runs from point to point between major headlands. Most of the water inside the closed area is less than 30 m deep. This closure was based on the understanding that lingcod nests occur primarily in shallow water, as reported in the literature. For area closures to be effective, a knowledge of the depth distribution of nests is important. I used a submersible to document both the distribution of lingcod nests below 30 m and the characteristics and behavior of nest-guarding fish.

Methods

I used the two-person submersible *Delta* to make 21 dives between 30 and 145 m to delineate the depth distribution of lingcod nests. The *Delta* is a 4.7 m submersible operational to 345 m with a cruising speed of 1.5 knots. The M/V *Jolly Roger* provided support facilities for the submersible.

The timing of the survey depended on the availability of the submersible. Commercial fishery data suggest that peak spawning occurs in late February

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ABSTRACT — A research submersible was used to delineate the depth distribution of lingcod, Ophiodon elongatus, *nests (egg masses) below 30 m. Although nests were not seen deeper than 97 m, behavior and dark coloration distinctive of nest-guarding lingcod were seen as deep as 126 m. Males guarding nests were distinctly colored, i.e., dark with little or no mottling, and most were obviously scarred. Two types of guarding behaviors were observed: 1) Males lying directly on or beside the nest and remaining nearly motionless unless touched and 2) males lying on a sentry post and defending the nest when other fish swam close.*

[1] Giorgi, A. E. 1981. The environmental biology of the embryos, egg masses and nesting sites of the lingcod, *Ophiodon elongatus*. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northwest Alaska Fish. Cent., Seattle, WA, Proc. Rep. 81-06, 107 p.

and early March in southeast Alaska (D. Gordon[2]), and I have observed lingcod nests, while scuba diving, in Sitka Sound through the last week in May. The submersible was only available during the later part of the nesting season; consequently, our field work was conducted from 21 through 30 April, 1992.

The study was conducted off the coasts of Kruzof and southern Chichagof Islands in southeast Alaska (lat. 135°25' – 136°05' W, long. 56°50'-57°31'N) (Fig. 1). Commercial fishing locations were used to pick dive sites. The marine geology in most of the outer coast sites is predominately rocky: Lava pavement is interspersed with bedrock, boulder fields, and rocky outcrops. Poor weather forced us to spend 2 days diving in Slocum Arm and interior Sitka Sound. Bottom habitat in these areas is generally silt and mud bottom, occasionally interspersed with rock outcrops.

Initially line transect methods (see O'Connell and Carlile, In press, for details) were used. However, due both to the scarcity of nests and their cryptic placement, I abandoned line transect methods in order to increase the probability of finding nests. The submersible was run at a slow speed (0.5 knots) close to the bottom. The observer looked for nests and lingcod through the starboard porthole. When a lingcod was sighted, the submersible pilot would alter course to slowly cruise a 100 m^2 area surrounding the lingcod to look for the presence or absence of a nest. The external lighting on the submersible was changed as necessary to illuminate holes and crevices. When a nest was found, information on volume, size, and condition was recorded, as were description of the lingcod's behavior, coloration, size, and the surrounding habitat. Sizes were visually estimated with the aid of two fixed laser beams. I assumed that all lingcod in close association with nests were male. Observations were recorded on both audio and 8 mm video tape; photographs were taken with an externally mounted Photosea[3] camera and a handheld 35 mm camera with synchronized flash.

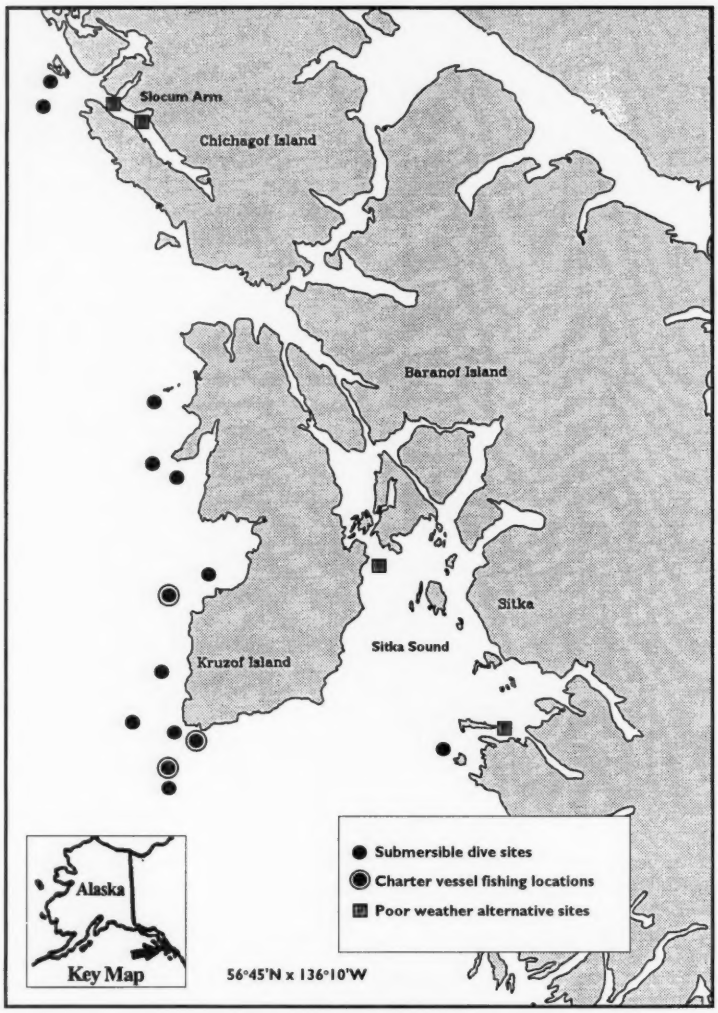

Figure 1.—Lingcod nesting study area, submersible dive locations, and charter vessel sample locations, April 1992, southeast Alaska.

A commercial troll vessel, the F/V *I Gotta*, was chartered to collect lingcod sex ratio and stage of maturity data for three areas surveyed by the submersible (Fig. 1). The vessel fished an area immediately following the completion of submersible transects in that area. The skipper was trained to determine lingcod sex and classify maturity stages as ripe, spent, or immature. Fish that were not readily identified as ripe, spent, or immature were recorded as "other."

Results

Fourteen dives were completed in rocky areas assumed to be typical of lingcod nesting habitat; poor weather forced us to make seven dives in areas

[2] Gordon, D. Alaska Dept. Fish and Game, 304 Lake Street, Room 103, Sitka, AK 99835.

[3] Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA, or the ADF&G.

predominated by silty bottom, generally uninhabited by lingcod. Thirteen nests were found during the 21 survey dives. Additionally, I saw three other lingcod that exhibited both behavior and coloration characteristic of the nesting males seen (Table 1). Horizontal visibility was excellent in the outside water sites (>15 m) and poor in Slocum Arm and interior Sitka Sound (<4 m). The average water temperature was 7.5° C.

Description of Nests and Nest Locations

Nests were found at depths between 33 and 97 m. The occurrence of nests was low, and 31% of the nest observed showed obvious signs of hatching. Most of the nests were small, between 0.5 and 2 l, and some were remnants of hatched nests. The largest nest (approximately 6 l) was also in the deepest water (97 m), although a trend of increasing nest size with depth was not apparent. Nests were deposited either in narrow, vertical cracks between angular boulders, under overhangs of boulders, or in V-shaped cuts within lava flows. Two nests, however, were deposited in small depressions on the rim of a large lava bowl; in both cases the guarding males were small, approximately 60 cm, and were lying directly on top of the eggs.

Table 1—Description of nests and nest-guarding lingcod observed during April 1992, southeast Alaska.

Approx. Nest Volume (l)	Depth (m)	Est. Size (cm)	Comments
3.0	30	None observed	Some hatching
0.5	30	75	Fish on nest, lava flow
1.0	33	95	Fish aggressive
0.3	40	75	Nest hatched
0.5	41	95	Fish on nest, boulders
1.0	42	60	Nest on rim of bowl, some hatching
1.0	45	60	Nest on rim of bowl, some hatching
2.0	54	95	Sentry post, vertical crack
2.0	57	95	Nest in vertical crack
Not observed	57	95	On ledge, sentry behavior
2.0	65	60	Under flat boulder
2.0	65	Same fish as above	Fish was 5 m away, guarding two nests
0.5	80	60	Under flat boulder
Not observed	84	95	In cave, territorial
6.0	97	115	Under round boulder
Not observed	126	80	In cave, aggressive and territorial

Description of Males and Fish Behavior

All but one of the nests observed were guarded by a lingcod. I saw one site where a single male was guarding two nests: The nests were 5 m apart, and the male was settled between the two and would swim slowly around both nests every few minutes. Nest-guarding males displayed two general behavior patterns. In the first, males were either directly above or next to the nest and remained virtually motionless as we approached; they would only move off the nest site if we physically touched them with the submersible or manipulator arm. Once the fish moved off the nest, it would generally circle back around even if we did not move away.

In the second type, males were observed on sentry posts, generally a ledge or high rock outcrop in the general vicinity of the nest. Usually these positions were within a line of sight of a nest. Some posts were 5-10 m away from the nests. The male would lie on the sentry post, and if any fish swam into the immediate area, it would aggressively chase them out of the area, circle back, visually check the nest, and finally return to the sentry post.

I observed one male for about 20 minutes. The fish was on a sentry rock about 3 m above the nest. The nest was deposited in a vertical crack between two huge boulders. While I observed the fish, a yelloweye rockfish, *Sebastes ruberrimus*, and another lingcod moved into the nest area. The nesting male chased these fishes out of the area aggressively and even bit at the yelloweye rockfish. It then returned to the nest, first lying vertically along the side of the nest with just its head protruding beyond the nest. The fish then laid directly above the nest, where it observed the submersible for about 5 minutes. Afterwards it moved back to the sentry post. It repeated this sequence of events three times while we watched.

I observed a variation in size and coloration of lingcod during the survey. Fish ranged from approximately 30 cm to 115 cm. Coloration ranged from dark gray with little mottling to tan with much mottling (Fig. 2). All of the individuals guarding nests were dark, with little or no mottling, and almost all had obvious scarring on the head and dorsal areas (Fig. 3). Coloration was not site specific; for example, at one offshore pinnacle I observed approximately even numbers of mottled vs. dark lingcod. The sex ratio of lingcod taken by the chartered troller in this areas was 56% males and 44% females, of which 27% were spent females and 25% were ripe males.

I observed one lingcod at 126 m that exhibited dark coloration, scarring, and territorial behavior typical of the nest-guarding males observed in this study. This fish was lying at the entrance to a cave and did not move off until the submersible bumped it. It then swam slowly off behind the submersible. At this point a yelloweye rockfish swam into the cave and up toward the ceiling. A moment later the lingcod returned, hesitated at the cave entrance, then rapidly swam toward the cave ceiling. The lingcod chased the rockfish out a back opening to the cave and then returned to it's original position at the cave entrance.

Interactions with Other Species

One of two offshore pinnacles surveyed rose steeply up from 126 m to 34 m, the other from 126 m to 61 m. In both, huge boulders were piled around the base and lower portions of these pinnacles. These areas were heavily populated by lingcod (both males and females), yelloweye rockfish, and prowfish, *Zaprora sileneus*. The prowfish inhabited caves and overhangs in close proximity to nesting lingcod and in some cases actually resided in the same space as lingcod, but no aggression or predation between the species was observed. Nest-guarding

Figure 2.—Lingcod exhibiting both types of coloration observed during lingcod nesting study, April 1992, southeast Alaska.

lingcod did chase other lingcod, yelloweye rockfish, and greenlings, *Hexagrammos* spp., swimming near nests. Local fishermen have reported both female lingcod and yelloweye rockfish full of ingested lingcod eggs. Conversely, schooling fishes, such as black rockfish, *S. melanops*, were observed near lingcod nests but the nesting lingcod seemed undisturbed by their presence.

Invertebrate predators, primarily the carnivorous gastropods *Amphissa columbiana*, *Fusitriton oregonensis*, and *Searlesia dira* were observed on several lingcod nests. I do not know if the snails were eating lingcod eggs or organic matter that may have settled onto the nest. Octopus, *Octopus dofleini*, occurred in most of the rocky habitats surveyed, and in several cases they occupied caves in close proximity (<5 m) to lingcod nests.

Discussion

Some behavior observed in this study differs from previous in-situ studies of nesting lingcod. Low and Beamish (1978) reported that nest-guarding males are usually found within 1 m of their nest. Although some of the fish I observed in this study were directly over or beside their nest, several of the fish were seen lying on sentry posts up to 10 m from the actual nest site.

The coloration of nest-guarding males needs further investigation. Color may vary by season; however it is not clear whether this dimorphism is sexual or related to stage of maturity. Of the fish sampled by the charter vessel for sex ratio, the skipper noted that the females were usually mottled with lighter coloration, and the ripe males exhibited dark coloration and skin scarring. The immature males sampled did not differ as noticeably from females. The scarring I observed probably results from aggression against other fish, although head scarring may also result from rock scratches obtained while picking predatory gastropods off nests. Local fishermen have reported male lingcod with large quantities of snail shells in their stomach during the nesting season.

The literature suggests that sexes segregate seasonally by depth. Females reportedly move into shallow water to spawn and then move back to deeper water, whereas males remain in shallow water (Cass et al., 1990). After spawning, the dispersal of female lingcod back to deep water may be related to prey availability. I found both nest-guarding males and female lingcod residing in close proximity, and in one deep-water area, the sex ratio (of mature fish) was almost equal. It is pos-

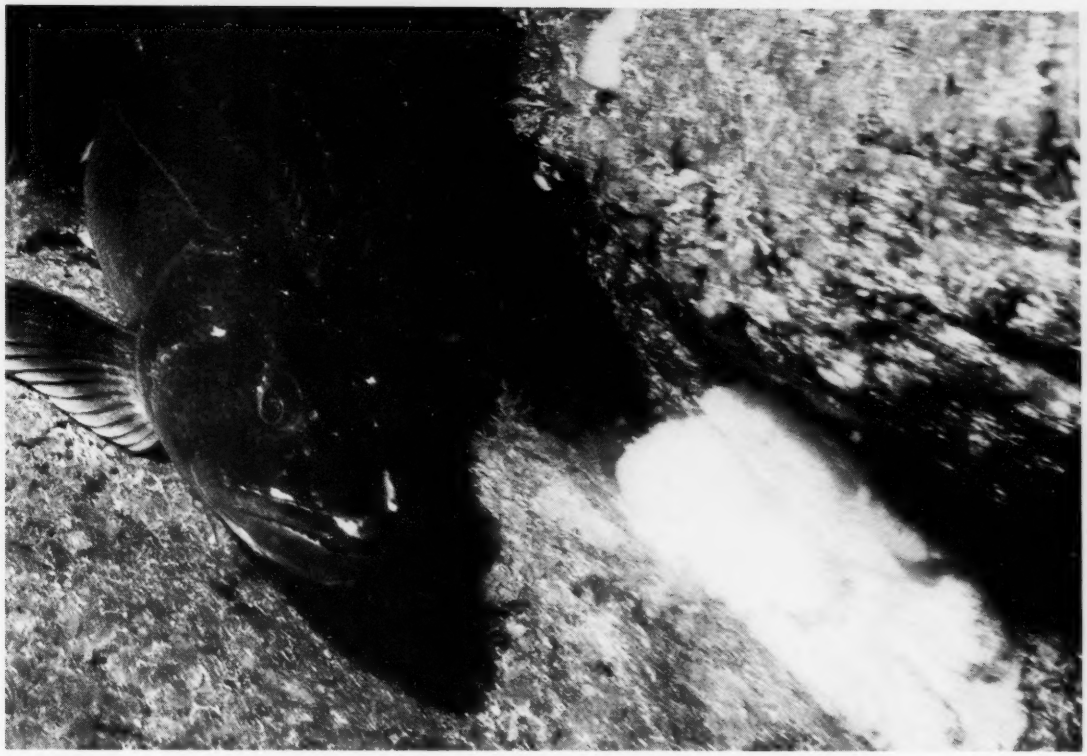

Figure 3.—Nest-guarding lingcod exhibiting dark coloration and head scarring, April 1992, southeast Alaska.

sible that the determining factor for distribution of nests is the presence of suitable habitat in areas of high current (Low and Beamish, 1978; Giorgi[1]). In highly productive areas, such as offshore pinnacles, the availability of suitable nesting sites near excellent feeding grounds may make it unnecessary for females to migrate elsewhere.

Many of the nests observed were partially hatched, and it is possible that the majority of nests had hatched prior to the survey. The low numbers of nests were not solely a factor of depth, as shallow transects also had few nests. Our commercial catch data (based on the percent of ripe males in the landings) indicates that late April to early May is the end of the nesting period on the outer Kruzof coast, and our scuba observations indicate that it is the middle of the nesting period in inside waters. The low numbers of nest observed in this survey may reflect the effects of the higher than average water temperature during the winter and spring of 1992; the 5-year average temperature for mid-April is 5.7°C, 2°C lower than the average in 1992 (National Weather Service, Juneau, Alaska, data).

Although a versatile tool, the submersible's size, the cryptic placement of some lingcod nests, and the ruggedness of the observed nesting sites, made it impossible to sight all nests along a transect. Thus, while I was unable to calculate the density of nests by depth, I have extended the known depth range of lingcod nests. Previous studies report lingcod nests in shallow water (Wilby, 1937; Jewell, 1968; Miller and Geibel, 1973; Low and Beamish, 1978; LaRiviere et al., 1981; Cass et al., 1990; and Giorgi[1]). I found lingcod nests as deep as 97 m and found indirect evidence of nests as deep as 126 m. Although a nest was not actually observed at 126 m, the coloration of the lingcod seen was typical of nesting males I observed elsewhere, as was its behavior. The nest-guarding behavior of the lingcod I observed was similar to that described by Low and Beamish (1978). They also reported that males discontinued territorial behavior and left the nesting areas a few days after hatching of the eggs; this information tends to support the conjecture that the lingcod seen at 126 m was nest-guarding.

In conclusion, depth may not be the limiting factor in distribution of lingcod nests. Given the extension of the depth range for lingcod nesting sites, fisheries managers will need to reevaluate the effectiveness of depth-specific closures for protecting nest-guarding lingcod. Additional research is

needed to determine the difference in spawn timing, nest density, and hatching success at various depths. The value of protecting the deep-water component of the nest-guarding population could then be weighed against the economic importance of the winter-spring fishery. In the interim, it seems prudent to impose a total seasonal closure of the fishery because the reproductive behavior and early life history of lingcod make local stocks vulnerable to overfishing.

Acknowledgments

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Travel Characteristics of Marine Anglers Using Oil and Gas Platforms in the Central Gulf of Mexico

WILLIAM R. GORDON, Jr.

Introduction

The nature of travel undertaken by the recreationist to and from the recreation site is an important focus of many research efforts. On land this value is usually easy to evaluate due to the constrained nature of roadways and the convenience of measuring distances between sites of origin and destination (Griffith and Jones, 1980). In contrast, marine recreational travel distances are often difficult values to assess. A contributing reason is the difficulty for marine recreational boaters to identify accurately the location and record the distance values of offshore destinations, especially in the absence of any physical structures or reference points (i.e., islands, charted reefs or snags, offshore facilities, buoys, line-ups, etc.). A lack of written records of the many compass headings, various rates of speed, and durations of travel within offshore trip segments may also contribute to an inaccurate assessment of the cumulative distances traveled offshore.

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ABSTRACT—This study was designed to evaluate the travel characteristics of avid marine anglers off Louisiana in the Central Gulf of Mexico. It focuses on the complex marine travel patterns involving the extensive assemblage of oil and gas structures. In an intercept approach, marine recreational fisherman were asked to identify near and offshore travel patterns on the day of the interview. Information was also solicited regarding how respondents selected and located fishing destinations as well as what method of fishing was undertaken that day. Petroleum platforms were a principal fishing destination, and platform anglers traveled an average distance of 75.5 km (40.7 n.mi.) to and from offshore fishing locations. In fishing an average of 6.5 platforms per trip, these anglers traveled about 21.3 km (11.5 n.mi.) between the first and last platform visited. Mean total distances for platform anglers were 96 km (51.8 n.mi). Travel distances for bay, nearshore, and bluewater anglers were also obtained.

Understanding the offshore range of marine anglers can be useful for two purposes. First, these values may be used in determining appropriate offshore zones for the deployment of artificial reef materials (Parker et al., 1974; Schwartz, 1980; Ditton and Burk, 1985; Gordon and Ditton, 1986; Myatt and Ditton, 1986). Second, offshore travel values may be used in the effective spacing of materials within a deployment zone. This distribution may reduce the crowding and overfishing of artificial reefs sited for use by anglers.

The principal goal of this research was to gain a descriptive understanding of the marine travel patterns of avid marine anglers using the oil and gas structures off the Louisiana coast. Although this information may be of greatest utility in the siting of obsolete platforms as artificial reefs, it is suggested that research investigating how marine anglers traverse this extensive system of platforms can provide a practical (not necessarily comparable) insight into such marine recreational travel. Secondary goals included an assessment of how marine anglers select and locate offshore fishing destinations and their fishing methods.

Study Area

In 1985, the National Research Council identified more than 3,100 oil and gas structures (platforms, pumping stations, etc.) in Federal waters off the Louisiana coast (National Research Council, 1985). Although intended to facilitate the exploration and recovery of hydrocarbons, this large assemblage of oil and gas structures also serves in a de facto capacity as artificial reefs or aggregating devices providing habitat for numerous species of fish and other marine life (Sonnier et al., 1976; Gallaway and Lewbel, 1982).

In a baseline study for the Minerals Management Service (MMS), Ditton and Auyong (1984) evaluated the recreational and commercial fishing use of selected major oil and gas platforms off the Louisiana coast. The MMS Central Gulf lease area was partitioned into three distinct study regions (Fig. 1). In a further analysis of the MMS data, Gordon (1987) investigated the utility of certain variables in forecasting the travel behavior of offshore recreational fishermen. To assess variable relationships, an on-site survey was conducted in the Delta Region, which was one of the same study areas used in the initial MMS study[1] (Gordon, 1987).

The Delta Region was selected for study because this region accounted for three-fourths of the recreational fishing craft observed within the three study regions (Ditton and Auyong, 1984).

[1] The same MMS offshore regionalization has also been utilized in other research efforts (Stanley and Wilson, 1989).

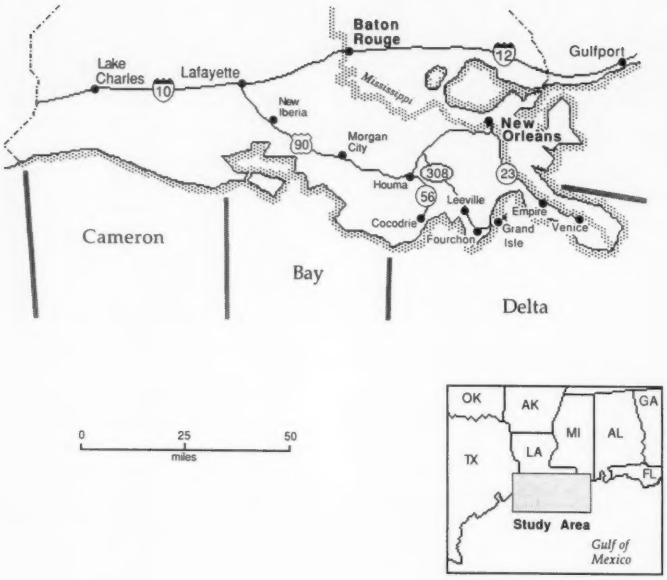

Figure 1.—Louisiana coast with area highway network, marine access system and MMS study regions.

The offshore study area is generally composed of a gently sloping continental shelf with minimal variations in bathymetry. The relatively flat bottom condition has facilitated the widespread deployment of oil and gas structures, and the depth of offshore waters where the majority of the recreational fishing occurs is usually less than 20 m. These depths would occur within 30 km (about 16.2 n.mi.) of shore.

Methods

Based on research by Ditton and Graefe (1978) and Ditton and Fedler (1983), a study questionnaire was designed to identify land and marine travel characteristics of recreational fishermen in the Delta Region.[2] Although only the marine-related aspects of this study are reported in this paper, landward mobility was measured by determining travel distances on land to marine launch sites and by whether or not a boat was trailered (Gordon, 1987).

Self-reported marine travel distances for bay, nearshore, and offshore anglers were obtained. Inquiries were also made regarding the offshore location-finding capabilities of study area fishermen. Other questions addressed factors that might be important to saltwater anglers in selecting their offshore fishing destinations (i.e., the importance of water depth and distance from shore in the selection of a platform destination).

A survey strategy was developed to determine which launch site locations would be most suited to maximize the number of completed surveys. In all, 200 interviews were conducted on-site during a 2-week period in late July and early August 1985.[3] This timeframe included two weekend periods of fishing activity. More marine recreational fishermen usually fish on weekends than during week days, generally allowing more fishermen to be intercepted in a reasonable period of time (Ditton and Auyong, 1984).

Upon their return to shore, recreational anglers were asked to recount the nature of their offshore fishing trip and to indicate on a helicopter flight map which platforms or lease blocks they had fished at (Houston Helicopters, Inc., 1985). Although some fishermen had difficulty recalling the platform or block numbers of all the fishing destinations visited that day, nearly all respondents knew the identification number of the lease blocks in which they had fished. With this information, travel distance values could be calculated with a computerized digitizer for each survey response.

Recreational fishermen were interviewed on their return to shore as opposed to their initial departure to offshore fishing destinations for several reasons. First, many of the anglers interviewed had preselected the offshore destinations that they would fish that day. In just as many situations, these individuals would alter their trip pattern and choose alternative destinations while in transit offshore. This change in trip pattern usually resulted from poor fishing at initial platform or

[2]As noted, only questions related to marine travel and offshore destinations are reported in this paper. The questionnaire utilized a variety of question formats. Open-ended responses were used to examine variables such as the number and location of platforms where fishing was conducted, frequency of launchsite use, as well as other launch sites used during the year, preferred waters depths, distances traveled from home to launchsite, distances traveled offshore, boat size, number of days spent fishing on an annual basis, seasons of fishing, and species sought after that day. A series of closed responses were read to respondents on topics regarding how fishermen find offshore destinations, what attracts anglers to particular platform destinations, and the types of onshore infrastructure required to support offshore travel. Likert-scaled questions examined the quality of fishing, the importance of onshore infrastructure and factors related to locating offshore destinations. Finally, a series of questions with a yes/no response examined topics on whether respondents fished in a tournament that day, whether platform locations were utilized, and if fishermen tied up to those structures, and whether water depth or distance from shore was a factor in selecting fishing destinations.

[3]With the possibility of temporal limitations for the 1985 data, the author returned to the study area during the month of August 1990 to determine if limitations existed. During a 3-day period of time, the author interviewed both tournament and nontournament anglers regarding their offshore travel behavior and destination preferences. With essentially the identical launch sites, offshore destinations and boating capabilities (equipment), it was concluded that travel trends and behavior had yet not changed appreciably since the original survey.

offshore destinations. Also, fishermen were generally more relaxed upon their return to shore and were willing to respond while securing their craft. Fishermen were also able to accurately locate platform or offshore destinations and identify trip segments of the just completed fishing trip.

Three trained interviewers remained at launch sites during the entire day to intercept all returning recreational fishermen. During the pretest, two temporal patterns emerged. One group of fishermen would depart from shore early in the morning and return in the late morning, while the other group would leave in late morning and return in the late afternoon or early evening. As fishermen returned to the launch site from their offshore fishing trip, a representative of each boat (group) was intercepted and interviewed. The operator of the craft was usually the individual who was interviewed. This person was preferred because it was he/she who had navigated the offshore waters and who had the most knowledge of the marine travel pattern used that day. All individual anglers that were approached for questioning, with the exception of only one boat owner who was rushed for time to return home, responded to the survey.

The locations of reported platform or block destinations were digitized to calculate distance values as follows: 1) Launch site to the first platform encountered, 2) platform to platform, 3) last platform to launch site, and 4) the travel distance for the entire trip (including bay and nearshore travel).

Interviews for this research were administered at five marine launch sites in the study area. Because questionnaires were completed at two launch sites where fishing tournaments were being conducted, some of the fishermen interviewed had actually completed their fishing trips from other launch locations and had driven to the tournament weigh stations. In all, sixteen public and commercial launch sites were represented in this study. The launch sites utilized by respondents were similar to those identified by Dugas et al. (1979) and Stanley and Wilson (1989).

Nearly half of the fishermen interviewed (46%) were participating in fishing tournaments conducted during the data collection. Although tournament locations provided an opportunity to gain access to a greater number of fisherman than otherwise would have been interviewed, it was necessary to evaluate any difference in marine travel behavior between tournament and sport fishermen (Dawson and Wilkins, 1980; Loomis and Ditton, 1987). These differences are reported later in this paper.

The SPSSx statistical software package was utilized in all data analyses. Analyses included response frequencies, means and respective standard error values, as well as t-tests for differences in means. All statistical tests were conducted at the 0.05 level.

Validity of the Intercept Approach

The questionnaire used in this study was administered on-site in an intercept format. An on-site approach was chosen over an area-wide (mail or telephone) technique for two reasons. First, an area-wide approach would require a sample to be drawn from a state-wide population (Ditton and Graefe, 1978; Liao and Cupka, 1979; Zapata and Ditton, 1979; Ditton and Fedler, 1983; Bockstael et al., 1986). Identification of the marine fishing population from the noncomputerized Louisiana state boat registration system, and the selection of a sample from this population was beyond the financial resources of this research. Other marine recreational studies examining Louisiana offshore fishing have encountered similar constraints (Roberts et al., 1985; Stanley and Wilson, 1989).

Although travel behavior data are limited by temporal and areal constraints, the on-site approach to data collection was justified by the breadth of the data obtained. The representativeness of the on-site study data was evaluated by successfully comparing fishermen characteristics (marine travel behavior, methods of fishing used, etc.) with data acquired in other research efforts (Ditton and Graefe, 1978; Dugas et al., 1979; Ditton and Fedler, 1983; Market Facts, Inc., 1983; Ditton and Auyong, 1984; Witzig, 1986).

Secondly, although an area-wide method might provide a more representative cross-section of the marine fishing population, the intercept approach was more likely to include more "avid" fishermen, as opposed to "casual" or less avid fishermen (Ditton and Fedler, 1983; Gordon, 1987; Milon, 1989). Because of the exploratory nature of the on-site research, it was desirable to gain insight into the activities of avid fishermen. It is these individuals who generally place greater fishing pressure on the marine resource system.

Results

Criteria Used in Selecting and Locating Offshore Fishing Destinations

The anglers interviewed in this study relied upon diverse considerations in choosing their fishing destination(s). Nearly 60% indicated that their choice of an offshore destination was based upon their past fishing experience at that location (Table 1). One-fourth of the respondents noted that the variety of fish species at a known platform, or the species they desired, was an important factor in selecting an offshore destination. Other considerations included the recommendations of friends who had previously fished at a chosen platform, as well as physical characteristics such as the varying clarity of water at the platform site and the proximity to shore. Preferred water depths for fishing were usually less than 60 m (Table 2).

Table 1—Reasons[1] why anglers choose specific offshore oil platforms for fishing.

Consideration	Frequency	Percent
Past success	117	58.5
Variety of species	50	25.0
Friend's recommendations	40	20.0
Clarity of water	27	13.5
Depth of water	12	6.0
Trying new platforms	12	6.0
Closeness to shore	12	6.0
Size of platform	1	0.5
Other	7	3.5

[1]Respondents could report more than one consideration; therefore, the number of responses exceeded the number of respondents.

Table 2—Water depths preferred for fishing in the study area.

Depth (m)	Frequency	Percent
0–15	78	39.0
16–30	43	21.5
31–60	28	14.0
61–90	7	3.5
91–120	2	1.0
121–150	1	0.5
>150	6	3.0
No one depth	30	15.0
Unknown	5	2.5
	n=200	100.0

Locating Offshore Oil and Gas Platforms

Fishermen used various methods to locate the offshore platform(s) visited on the day they were interviewed (Table 3). Slightly over half of the respondents indicated that they used a compass in navigating offshore waters. Nearly 20% stated that visual sightings of known reference points were used to reach offshore objectives. Two-thirds of the respondents (66%) indicated that they used the shape of configuration of a platform (or complex) to locate their position while on the water. As noted by some of the respondents, this particular practice may confuse the person navigating if there has been a period of time between offshore visits.

Table 3—How anglers located offshore oil platforms in the study area.

Method	Frequency	Percent
Compass headings	101	50.5
Sight	35	17.5
LORAN	20	10.0
Depthfinder	12	6.0
Unknown	32	16.0
	n=200	100.0

Fishing Destinations

Four location groups emerged as the principal fishing destinations: 1) Petroleum platforms, 2) nearshore locations (jetties and beaches), 3) bay locations, and 4) bluewater locations. Platform locations were the destination for about three-fifths (61%) of the respondents who fished near or at them. Nearly as many anglers (59%) stated that they had actually tied to a platform to fish. One-fifth (21%) of the responding anglers specified that they had fished nearshore (usually near jetties), while 11% fished bay locations. Bluewater anglers (11%) were the smallest response group.

As another measure of the attractiveness of offshore petroleum platforms as fishing destinations, nearly three-fourths (74%) of the fishermen interviewed tie to platforms at some time during the year. Only 11% noted that although they have the opportunity, they choose not to tie to platforms.

Fishing Methods

Marine anglers in the study area were categorized into five groups: 1) Nearshore and bay fishermen, 2) offshore platform fishermen, 3) offshore (platform vicinity) trollers/anchorers, 4) platform sportfishing divers, and 5) bluewater fishermen. The first group consisted of those fishermen who have small craft (4.3–5.2 m) and, due to safety considerations, opt to do their fishing either in "inside" waters (bays, inlets, bayous, etc.) or at jetty locations and nearshore platforms. Many of these fishermen either anchor to fish or troll the shallow waters.

The second group included those fishermen who traveled offshore to fish at or near oil and gas platforms. Fishermen who tied to the structures were seeking those fish inhabiting the support-structure of the platform (benthics or dermersals). Those fishermen trolling or anchoring near the structures (third group) were generally seeking the pelagic species that prey upon the "reef" fish that inhabit the platform (Klima and Wickham, 1971; Dugas et al., 1979; Gallaway and Lewbel, 1982; Seaman et al., 1989). The fourth group, sportfishing divers, also sought their catch at or near platforms (Roberts and Thompson, 1983).

The final group, bluewater fishermen, sought clear and deep waters to pursue billfish, tarpon, tuna, or shark. Dugas et al. (1979) noted that ". . . the location of bluewater varies from 35 to 70 miles (offshore), depending upon seasonal meteorological and/or hydrological regimes." Dugas et al. (1979) also observed that although bluewater distances vary from shore and that most trolling is done in open water, most of these fishermen "will make a concerted effort to troll adjacent to oil platforms whenever the opportunity presents itself." A frequency distribution of fishing methods used in the study area by respondents is presented in Table 4.

Table 4—Angling methods used in the study area.

Method	Frequency	Percent
Tie to platforms	109	54.5
Troll near platforms	60	30.0
Anchor near platforms	3	1.5
Bluewater (tarpon, etc.)	15	7.5
Dive and tie at platforms	10	5.0
Unknown	3	1.5
	n=200	100.0

Marine Travel Characteristics

Saltwater anglers who did not fish at or near platforms (n=54, SE=1.01), but fished nearshore or in the coastal bay systems, reported a mean total trip length of 16.8 km (9.0 n.mi.). Anglers fishing at platform locations reported a mean travel distance of 34.2 km (18.5 n.mi.) from launch site to the first platform used (n=109, SE=0.97), an additional mean distance of 21.3 km (11.5 n.mi.) when traveling from platform to platform (SE=1.34), and a mean travel distance of 41.3 km (22.3 n.mi.) from the last platform encountered back to the launch site (SE=1.21). A mean total trip length of 96.8 km (52.2 n.mi.) was calculated for platform fishermen (n=109, SE=2.78).[4]

The mean trip length for offshore trollers and bluewater fishermen (n=17, SE=8.49) was 104.5 km (56.4 n.mi.). When asked if distance offshore was a factor in selecting platform or offshore destinations, almost three-fourths (71%) of all respondents noted that distance was a consideration. Respondents indicated that the furthest distance offshore they would be willing to travel was about 50 km (27.0 n.mi., n=196, SE=1.81). Table 5 presents a range of these offshore distance values.

[4]In the present analysis, travel distances are assessed according to the type of angler, as well as by temporal and behavioral factors (i.e., tournament vs. nontournament fishermen). The present distance analysis varies from Gordon's (1987) work in that the earlier work did not isolate travel contributions by divers and inshore and offshore trollers.

Table 5—Maximum distance an angler would travel offshore in this study.

Distance (km)	Frequency	Percent
0 –16	57	28.5
16.1– 32	30	15.0
32.1– 48	27	13.5
48.1– 64	25	12.5
64.1– 80	23	11.5
80.1– 96	10	5.0
96.1– 112	5	2.5
112.1–128	3	1.5
>128	11	5.5
Unknown	9	4.5
	n=200	100.0

Platform fishermen fished about 6.5 platforms (SE=0.56) on the day they were interviewed (Table 6). When dividing the mean distance traveled between platforms (21.3 km) by the approximate number of platform visits, study anglers traveled 3.3 km (1.8 n.mi.) between each platform visited.

Table 6—Number of oil and gas platforms visited per fishing trip.[1]

Number of platforms fished	Frequency	Percent
1–2	29	24.4
3–4	23	19.3
5–6	24	20.2
7–8	16	13.4
9–10	10	8.4
11–14	3	2.5
15–18	7	5.9
19–21	4	3.4
>21	3	2.5
	n=119	100.0

[1] It should be noted that the higher values for platform fishing were the result of fishing the entire day (minimal travel time) or fishing over a 2-day trip.

As noted earlier, nearly half of the fishermen interviewed (46%) were participating in fishing tournaments. Responses were tested for bias on travel-related behavior, and it was concluded that there was a significant difference in behavior between the two groups. Results of a t-test for differences in means (n=114: this value represents the number of individuals interviewed on days when tournaments were taking place), suggested that the mean value of total marine trip distance for nontournament fishermen (79 km or 42.6 n.mi., n=60) was significantly different at the 0.05 significance level, than the mean travel value for tournament fishermen (114 km or 61.5 n.mi., n=54) (t=4.01>1.98, F=16.1).

An analysis of offshore and nearshore craft used by respondents in the Delta Region revealed that the "average" craft size was 6.9 m (22.7 feet, SE=0.52). Nearly 80% of the respondents operated marine craft less than 8 m long (Table 7). The fishing craft operated by respondents generally carried between three and four persons. The 200 respondents interviewed represented a total of 708 marine recreational fishermen. This was an average of 3.7 fishermen per craft (SE=0.12, n=161, missing data=39).

Table 7—Classification of boat sizes[1] in the study area.

Boat size (m)	Frequency	Percent
<4.3 m	1	0.5
4.3–5.5	57	28.5
5.6–7.6	99	49.5
7.7–8.8	16	8.0
8.9–10.4	10	5.0
10.5–11.9	3	1.5
12.0–13.4	6	3.0
>13.4	6	3.0
Unknown	2	1.0
	n=200	100.0

[1] Based on boat size classes used by Ditton and Graefe (1978).

Discussion

A limited literature has developed in recent years focusing on the offshore range of travel of marine recreationists. These studies have generally concentrated on two travel components, which include: 1) Landward travel to and from a launch site or marina (Noden and Brown, 1975; Bender and Winsor, 1979) and 2) offshore travel characteristics (Buchanan, 1973; Ditton and Graefe, 1978; Liao and Cupka, 1979; Ditton et al., 1980; Ditton and Fedler, 1983; Ditton and Auyong, 1984; Bockstael et al., 1986; Gordon, 1987; Milon, 1989; Stanley and Wilson, 1989).

Offshore trip characteristics are infrequently examined within the marine recreational literature. These activities are either recorded in terms of total trip distances or one-way distance values (shore to destination). Marine recreational travel between various offshore destinations is usually not assessed. Although complex trip patterns are likely to exist, mail survey techniques or other sampling procedures make it difficult for the respondent to identify the sequence of past offshore trip patterns.

In a distance study of offshore boat fishermen in the Houston/Galveston region of the Texas coast, Ditton an Graefe (1978) observed that offshore fishermen reported travel distances of 29.5 km (15.9 n.mi.) and 40.9 km (22.1 n.mi.) offshore in their average and longest trips. In a state-wide study of marine recreational boat fishermen, Ditton and Fedler (1983) reported that offshore fishermen reported travel distances of 22.5 km (12.1 n.mi.) and 34.3 km (18.5 n.mi.) in their average and longest trips, respectively.

In commenting on these studies, Ditton and Auyong (1984) attributed these trip differences to be the result of varying widths and depths of the outer continental shelf. Ditton and Auyong (1984) observed that "Louisiana fishermen are probably attracted farther offshore than Texas fishermen by the extensive array of petroleum platforms." The present study provides support for the assertion that Louisiana fishermen travel further offshore to fish than their Texas counterparts. Although present findings revealed that marine anglers traveled a mean distance of 34.2 km (18.5 n.mi.) offshore, it is again important to note that these distances represent only one segment of the offshore trip. There are no prior studies conducted in the region which report on total trip characteristics.

Offshore travel behavior can be influenced by the type of fishing activity being conducted. When examining variations in the behavior of marine anglers, tournament fishermen exhibited 40% greater mobility than other sport anglers, thereby exerting fishing pressure at distances form shore. Whatever the motive for fishing, there is one factor which has not been effectively addressed within the literature. Travel within the de facto artificial reef setting of offshore oil and gas structures is likely to be greater than travel within an equally dispersed, yet totally submerged system of artificial reef destinations. This behavior might be prompted by the realization that if trouble occurs offshore, emergency assistance can usually be secured from platform personnel. In such a situation, it is likely that the array of off-

shore platforms in the central Gulf of Mexico serves as an "attractive nuisance," luring fishermen further offshore.

The majority of studies within the Louisiana/Texas offshore region, including the present research, reported average offshore travel distances to be within 48 km (25.9 n.mi.) of shore. The only exception is a study by Stanley and Wilson (1989) which observed extensive marine recreational travel behavior in the waters offshore Louisiana. Stanley and Wilson (1989) observed average one-way travel distances of "at least 62 km (33.5 n.mi.) for marine recreational fishermen within the Delta study region. Their minimum total travel distance value of 124 km (66.9 n.mi.) did not account for additional platform to platform travel segments, which consisted of more than 20% of the total offshore trip in the present study.

The equipment capabilities of the Stanley and Wilson respondents are more indicative of charter boat operations or the larger range of private recreational craft than the typically smaller craft encountered in the present research.[5] Although Stanley and Wilson (1989) acknowledged that their respondents were not representative "of all recreational anglers and divers off the Louisiana coast," their travel values appear to be overstated. In the present research, the furthest offshore distances considered by respondents (49.2 km or 26.6 n.mi.) were found largely to be consistent with research by Ditton and Graefe (1978), Ditton and Fedler (1983), Ditton and Auyong (1984), and Bockstael et al. (1986).

Similar to observations by Ditton and Auyong (1984), petroleum platforms served as principal offshore destinations for the present study. The offshore respondent traveled approximately 100 km (54.0 n.mi.) on water in pursuit of his recreation. The ease with which this was accomplished (i.e., speed and range of the craft) provided the opportunity for the fisherman to choose from multiple offshore destinations. Familiarity with the offshore system allowed platform or destination choice to be based upon past success at particular fishing locations, as well as the choice of desired species and information passed on by friends. In a study of an artificial reef system in Florida, Milon (1989) observed that the importance of anticipated catches and previous success were important in choosing artificial reef destinations.

Also in the present research, offshore anglers demonstrated an effective use of several platform destinations per trip. Offshore trips seldom involved traveling to a single destination. It appeared that if a particular platform destination was providing poor fishing results, then another nearby platform would be visited. Mileage results revealed that these visits were generally completed within 20 km (10.8 n.mi.) of the first and last encounter with a platform destination. Nearly three-fourths of each platform fishing trip's total distance was spent traveling to and from offshore destinations.

Results suggest that most platform fishermen travel to those structures easily located within their visible horizon. The proximity of structures (clusters) located near each other may encourage this apparent travel behavior for two reasons. First, there is the ease of visual navigation between structures, and second, there is the realization of having additional opportunities nearby. Additional opportunities may be important if the fishermen is having limited success at a particular platform.

Implications

The offshore travel of marine anglers in the Gulf of Mexico study area is composed of travel components to and from offshore destinations, as well as travel amongst offshore destinations. Understanding the importance of these multiple travel components is useful for the effective planning of artificial reef opportunities intended for marine recreationists. The majority of studies to date reflect only a basic understanding of one-way distance values from shore to an offshore destination.

The use of statistical means representing average offshore travel values has been used to establish distance zones or arcs for the deployment of reef materials. Identified on the basis of effective travel distances, outer ranges of travel within a concentric arc have been identified at 32 km (17.3 n.mi.) (Myatt and Ditton, 1986), 40 km (21.6 n.mi.) (Wilson et al., 1987) and 48 km (25.9 n.mi.) offshore (Schwartz, 1980). Stanley and Wilson (1989) have established a range of maximum travel distances of 62–83 km for the Louisiana Artificial Reef Initiative, although platforms have been deployed as artificial reefs as far offshore as 193 km (104.2 n.mi.)

The preponderance of literature within the Central Gulf of Mexico region suggests that maximum arc distances for recreational fishermen should be established at 48 km (25.9 n.mi.) offshore. Deployment of reef materials within this system should take into consideration the clustering of materials at reef sites based upon effective distances between offshore reef destinations.[6] The spacing of materials within the cluster, as well as the distances between competitive reef opportunities would serve to distribute fishing pressure by distinguishing reef users according to safety, skills, experience, equipment capabilities, and fishing expectations. Crowding and declining fishing use may result if a proper assessment of the density of deployed reef materials is not conducted.

Beyond this outer arc, materials can be deployed for deep water habitat or charter and commercial uses (Wilson et al., 1987). The highly specialized marine recreational fisherman profiled by Stanley and Wilson (1989) possessed equipment beyond the norm.

[5]Within the Delta Region, Stanley and Wilson (1989) observed a mean engine power rating of 289 horsepower for recreational craft. This value was much higher than the power ratings observed by Ditton et al. (1980). Although horsepower characteristics were not a formal variable within the present research, the Stanley and Wilson values appear to be higher than engine ratings observed during the present field survey. Such characteristics suggest that Stanley and Wilson may have observed behavior beyond the norm for the Delta region.

[6]Although the platform-to-platform travel distances in the present study represented over 20% of the total offshore trip, it is suggested that similar patterns of destination-to-destination travel are likely to exist in other marine reef settings.

These individuals who have an offshore craft provisioned with sophisticated navigational and safety equipment are capable of using reef structures located further offshore. It is only these individuals who are properly equipped to take advantage of deployments as far offshore as the 193 km (104.2 n.mi.) siting by the Louisiana Artificial Reef Initiative. More distant offshore locations may also be of benefit to the tournament fishing community, who in this study represented a greater range of offshore travel than nontournament anglers.

With a finite supply of materials available for artificial reef development, it is important that state artificial reef programs examine all components of offshore travel undertaken by marine recreational anglers within their jurisdiction. It is only with such detailed information that artificial reef planners can insure that materials (targeted for recreational use) are optimally sited for maximum recreational benefit. In concluding, although this paper has addressed marine recreational travel amongst the offshore oil and gas structures located adjacent to Louisiana, it is most probable that complex travel patterns exist in more traditional reef settings. The need exists to implement research which identifies travel behavior in other marine settings. For example, a better understanding of travel behavior in the marine environment off the Florida or southeast Atlantic (U.S.) coastline may assist in a more effective deployment of reef materials intended for recreational benefit.

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